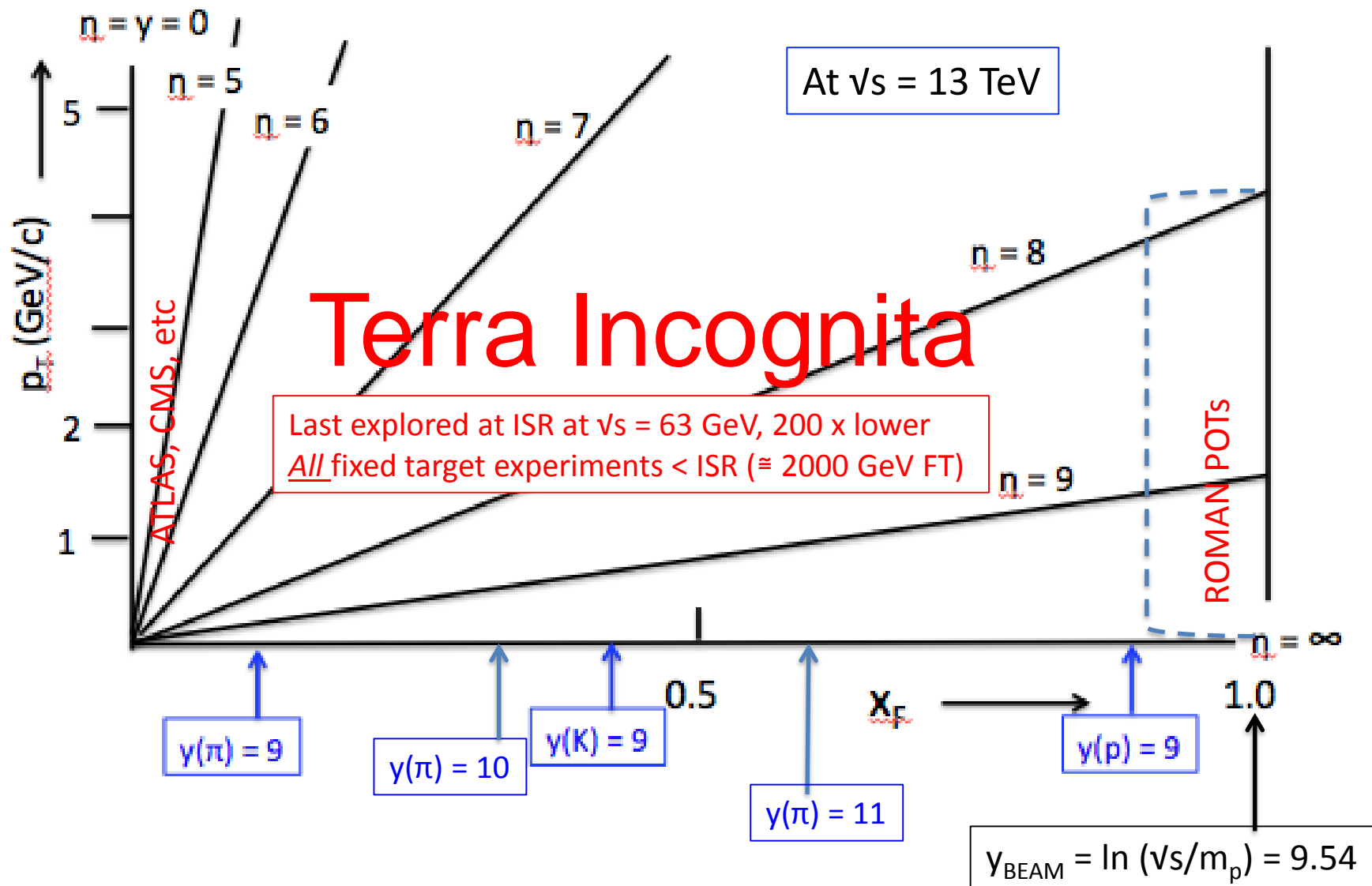# SAS@LHC / VFHS
A Very Forward Hadron Spectrometer
for Multi-TeV Forward Particles at the LHC

Michael Albrow, Fermilab

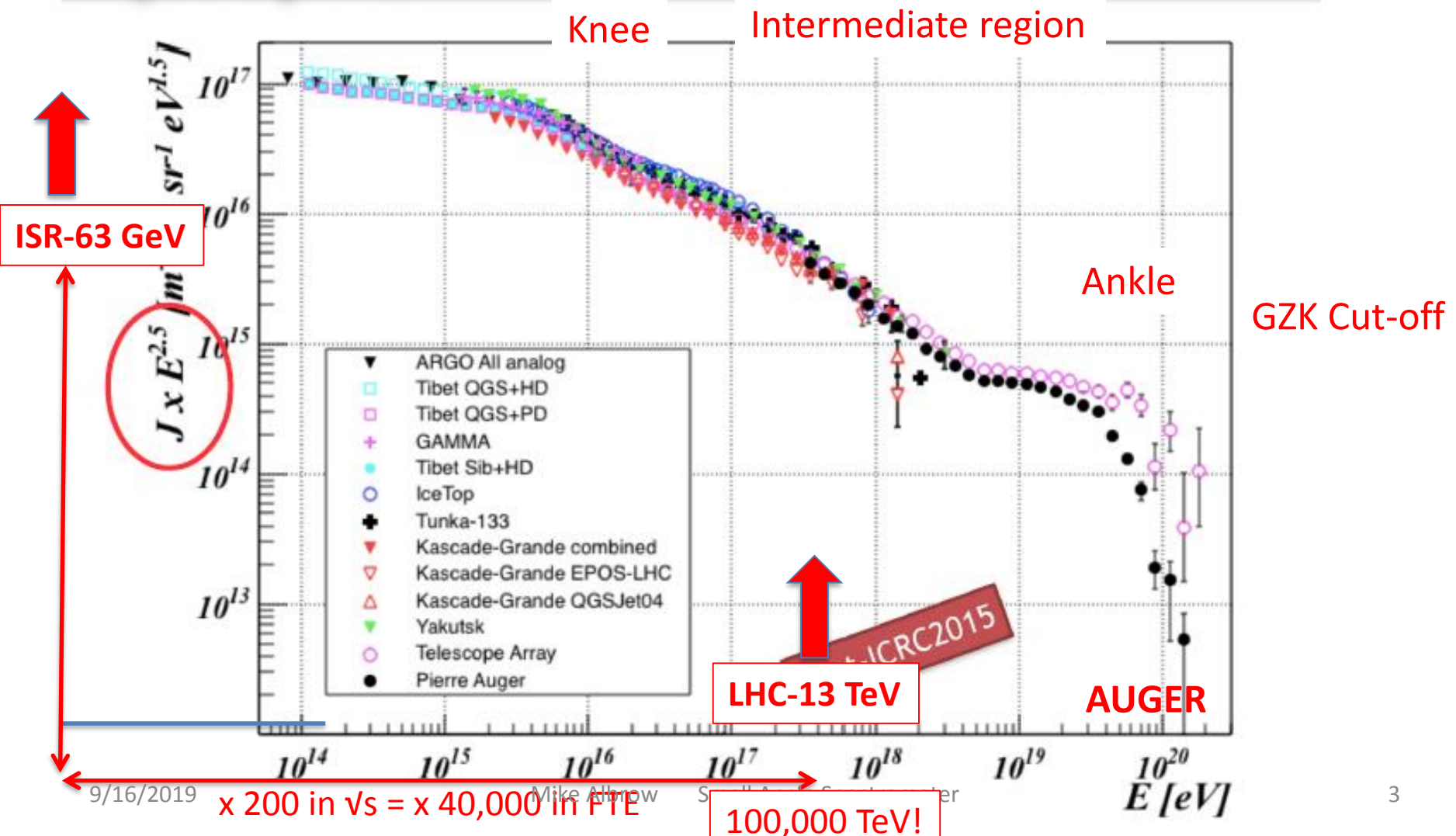A few introductory slides here

Low-x Nicosia, August 2019

ZDC & LHCf measure neutrals ($n + K^0_L$, $\pi^0 \rightarrow \gamma\gamma$) at $\theta \sim 0^o$.

COSMIC RAY SHOWERS: ASTROPHYSICS CONNECTION

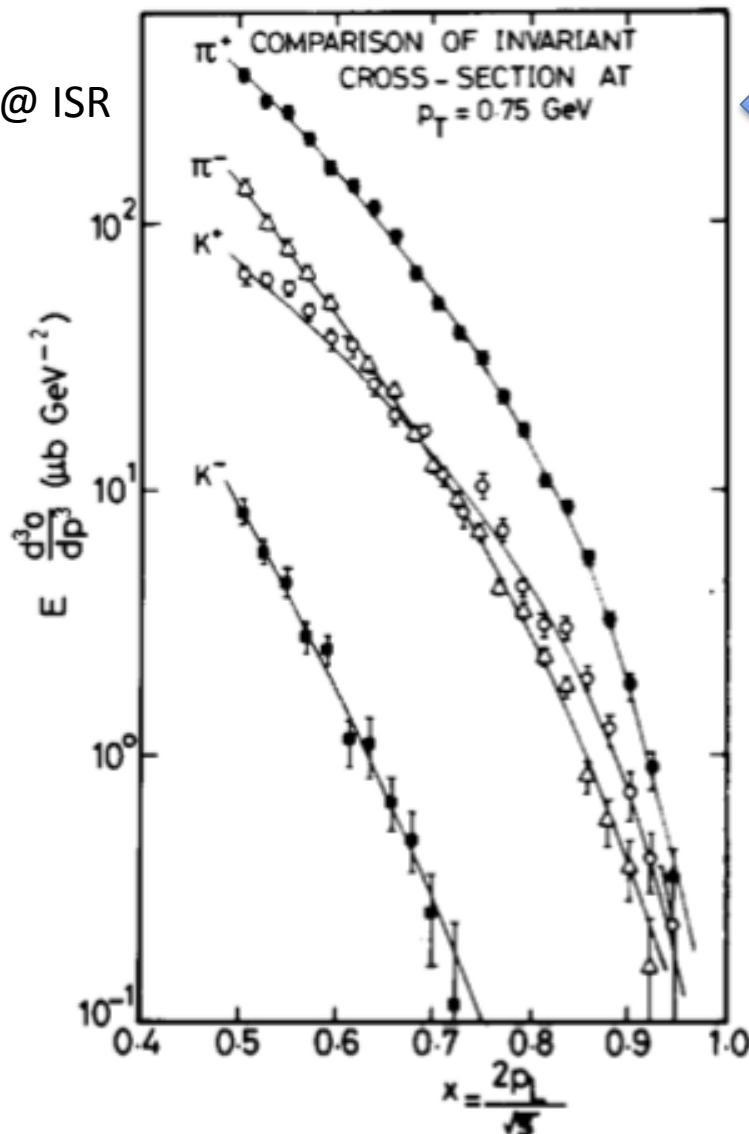Spectrum of high energy Cosmic Rays $\phi(E) \times E^{2.5}$

All particle spectrum

Knee

Intermediate region

ISR-63 GeV

Ankle

GZK Cut-off

Legend:
- ▼ ARGO All analog
- ☐ Tibet QGS+HD
- ☐ Tibet QGS+PD
- + GAMMA
- ● Tibet Sib+HD
- ○ IceTop
- ✚ Tunka-133
- ▼ Kascade-Grande combined
- ▽ Kascade-Grande EPOS-LHC
- △ Kascade-Grande QGSJet04
- ▼ Yakutsk
- ○ Telescope Array
- ● Pierre Auger

LHC-13 TeV

ICRC2015

AUGER

100,000 TeV!

x 200 in √s = x 40,000 in FTE

9/16/2019   Mike Albrow   Small Area Spectrometer   3

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

41 years ago !

Small transverse momentum
p_T (Mean p_T ~ 350 MeV/c)

Feynman $x_F = p_z/p_{BEAM}$

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.

DPMJET prediction

Very uncertain! Illustration only

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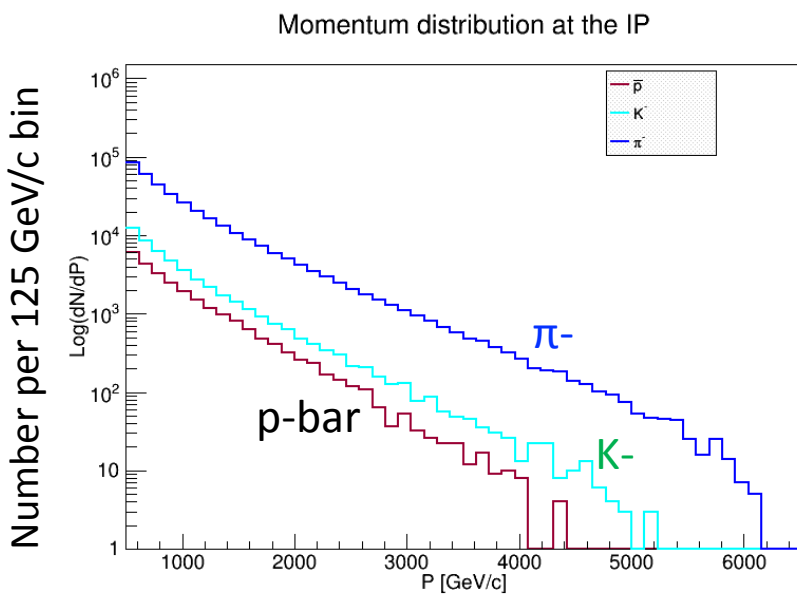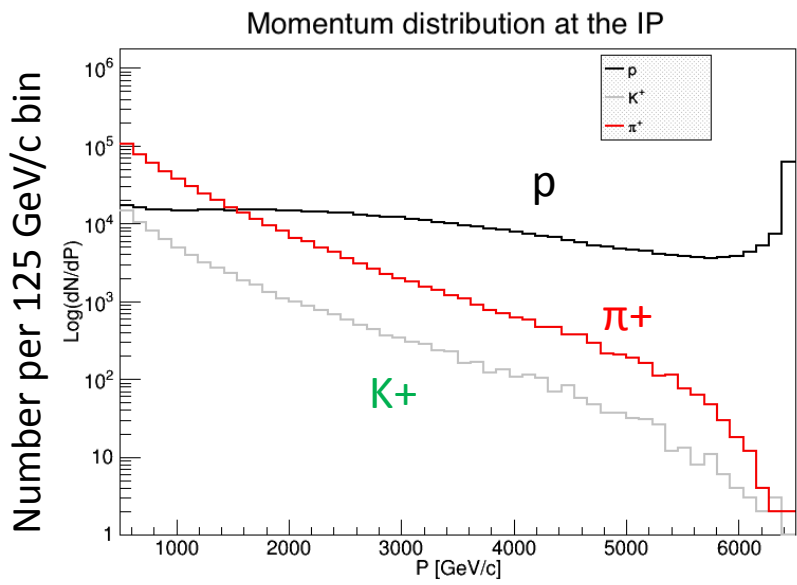With 10^6 pp events, √s = 13 TeV
(N.Mokhov and O.Fornieri)

In 1 second, with 2808 bunches,
Have 30×10^6 bunch crossings and
$30 \times 10^6 \times \mu$(= 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
Anti-deuterons/tritons/He^3 to measure too

Momentum distribution at the IP

~ 100 x Acc/bin/sec if μ ~ 3

Momentum distribution at the IP

Neutrons not = protons, K⁰ not = K⁺/⁻

A Spectrometer for Multi-TeV Forward Particles at the LHC

An idea for a new LHC experiment - collaboration needed!

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

Some physics topics: single- and two- particle inclusive production (& anti-nuclei)

Q & H ?　　　　Stan Brodsky's talk　　　　Ilias Cholis talk

TeV particles through 30 Tm spectrometer magnets, special vacuum chamber

Tracking, Calorimetry and Muon detectors

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

Anatoli Romaniouk's talk

What's next? A new collaboration – experiment co-existing with ALICE or LHCb?

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) – or included in

Transition Radiation Detectors for γ = E/m in 10^3 – 3. 10^4 region   (novel – Romaniouk's talk)

Hadron Calorimeter for energy measurement and muon filter

Muon tracking behind calorimeter
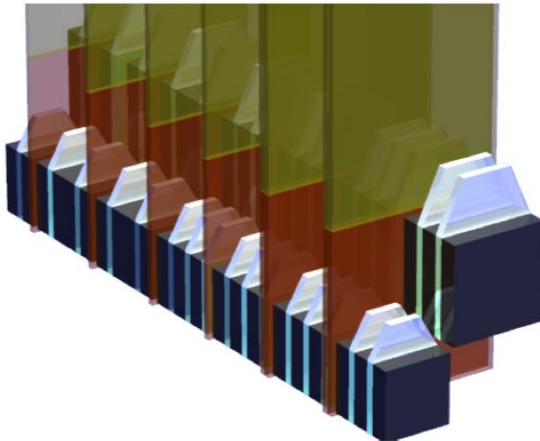
Possible later extension (not discussed here):
Bent crystal to channel and so accept highest momenta (>~ 4.5 TeV, ~4 mrad bend)

LHCf is a small 0° calorimeter measuring photon-like and n-like showers
Only 1.6 λ_l and 4 cm in size, $\sigma(E)/E \sim 40\%$ for neutrons.
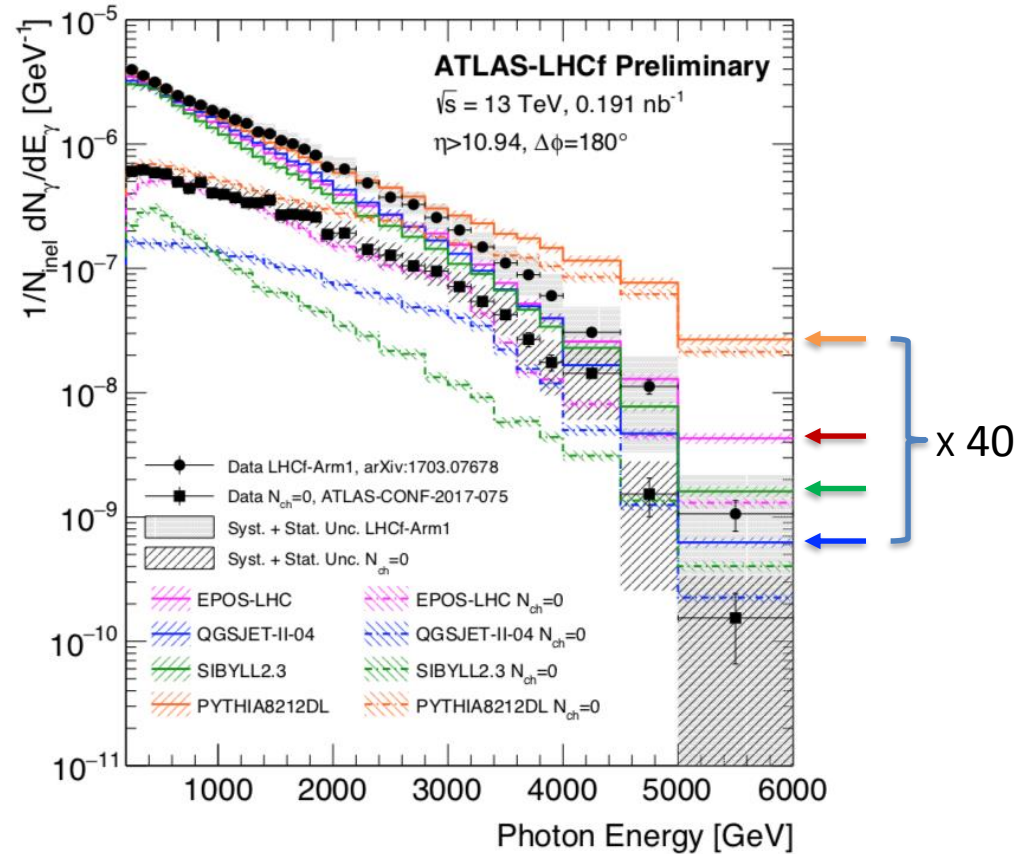Low-PU, High β* runs

Large spread in predictions:

Arm 1: 2cm x 2cm & 4cm x 4cm
Arm 2: 2.5 x 2.5 & 3.2 x 3.2 cm

Common data with ATLAS for some
Low-PU runs: diffractive events

ZDC in CMS
7 λ_l and 8cm x 10 cm
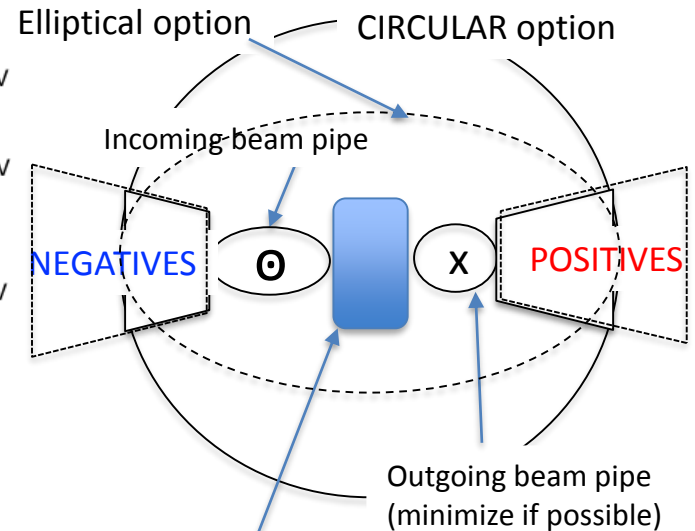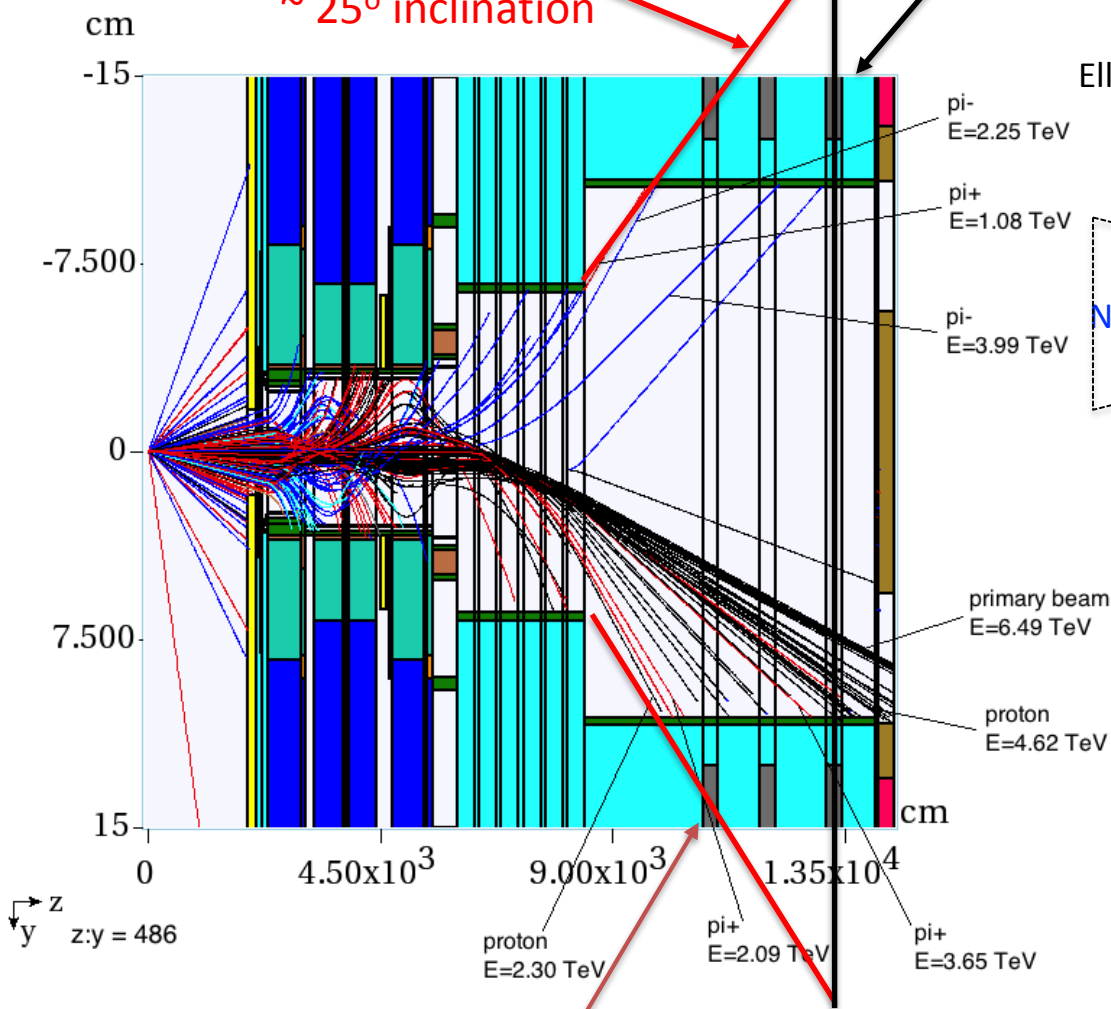Expect $\sigma(E)/E \sim 15\%$ at 3 TeV

A good 3D-imaging calorimeter
for SAS : $\sigma(E)/E \sim 5\%$

Conical pipe 80 – 130 m
Circular or elliptical
~ 25° inclination

10-12m for spectrometers

Back plate schematic

50 cm

cm
-15

-7.500

0

7.500

15

0   4.50x10³   9.00x10³   1.35x10⁴

z
y   z:y = 486

pi-
E=2.25 TeV

pi+
E=1.08 TeV

pi-
E=3.99 TeV

primary beam
E=6.49 TeV

proton
E=4.62 TeV

cm

proton
E=2.30 TeV

pi+
E=2.09 TeV

pi+
E=3.65 TeV

Shielding – can be moved out (?)

Elliptical option   CIRCULAR option

Incoming beam pipe

NEGATIVES   ⊙   X   POSITIVES

Outgoing beam pipe
(minimize if possible)
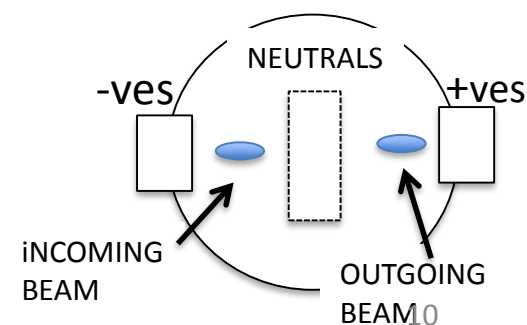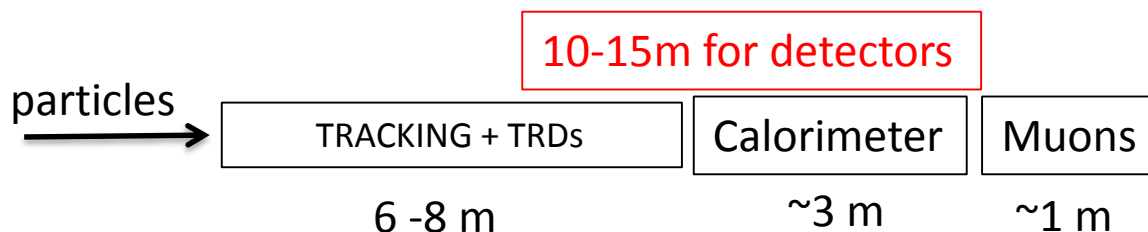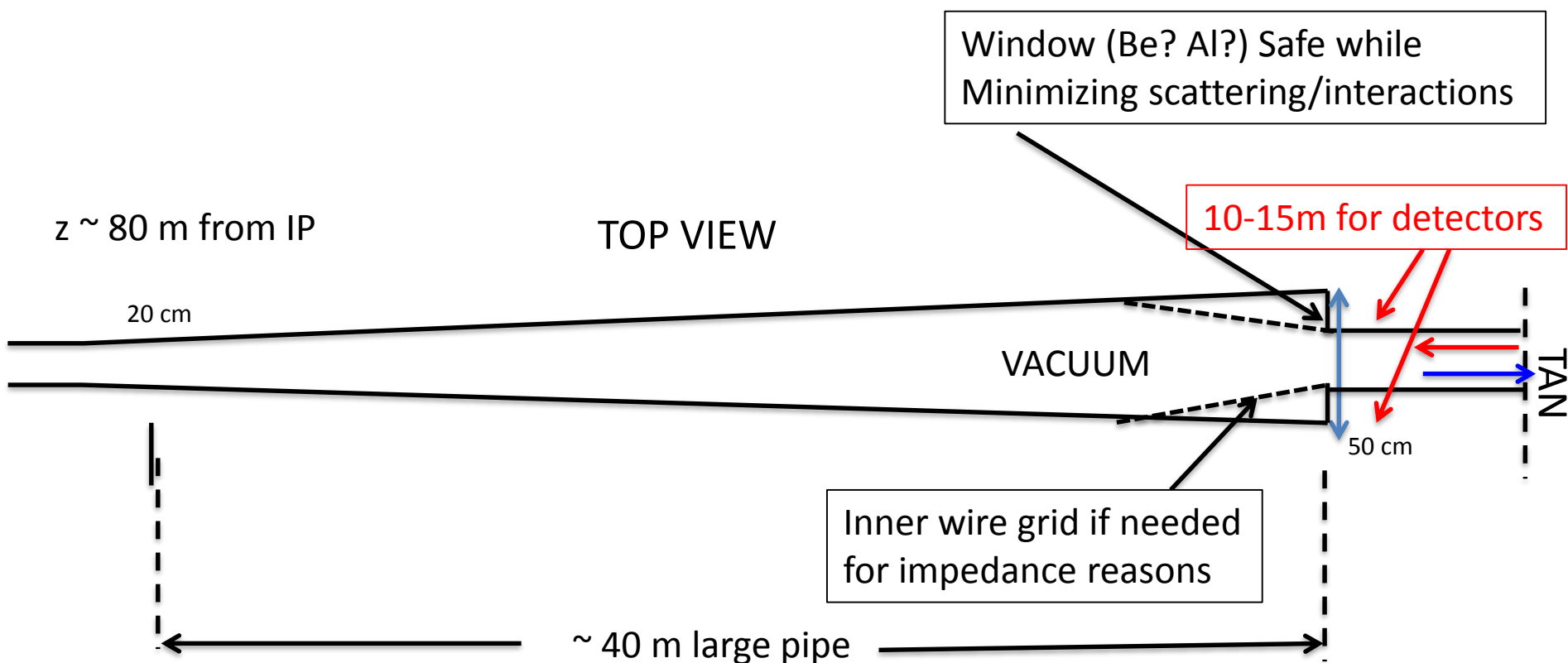
Only neutrals here (+B/G)
(0° calorimeter- LHCf'/ZDC')

Extends their physics program
to correlations, e.g. $h^0 h^+$ states

Beam pipe design for small angle spectrometer (schematic)

20 cm - 50 cm diameter conical pipe from 85m to 130m (from collision)

Window (Be? Al?) Safe while Minimizing scattering/interactions

z ~ 80 m from IP

TOP VIEW

10-15m for detectors

20 cm

VACUUM

TAN

50 cm

Inner wire grid if needed for impedance reasons

~ 40 m large pipe

10-15m for detectors

particles

| TRACKING + TRDs | Calorimeter | Muons |

6 -8 m   ~3 m   ~1 m

NEUTRALS

-ves   +ves

iNCOMING BEAM

OUTGOING BEAM

# TRD development for hadron identification in multi-TeV energy range.

Transition Radiation Detectors : Only known way to identify multi-TeV π/K/p

SAS_TRD

Anatoli Romaniouk's talk this morning, on behalf of team:

J. Alozy[a], N. Belyaev[c], B. L. Bergmann[d], M. van Beuzekom[e], T.R.V. Billoud[f], P. Buriand,[g], P. Broulim[g], M. Campbell[a], G. Chelkov[h], M. Cherry[i], S. Doronin[c], F. Dachsa,[b], K. Filippov[c], P. Fusco[j,k], F. Gargano[k], B. van der Heijden[e], E. H. M. Heijne[a,d,e], S. Konovalov[l], X. Llopart Cudie[a], F. Loparco[j,k], V. Mascagna[m,n], M. N. Mazziotta[k], L. Meduna[d], H. Pernegger[a], D.Ponomarenko[c], S. Pospisil[d], M. Prest[m,n], C. Rembser[a], A. Romaniouk[c], A. A. Savchenko[c,o], D. Schaefer[p], E. J. Schioppa[a], D. Sergeeva[c,o], D. Shchukin[l], E. Shulga[c], S. Smirnov[c], Y. Smirnov[c], P. Smolyanskiy[h], M. Soldani[m,n], P. Spinelli[j,k], M. Strikhanov[c], L.Sultanalieva[c]. P.Teterin[c], V. Tikhomirov[l], A. A. Tishchenko[c,o], E. Vallazza[q], K. Vorobev[c], K. Zhukov[l]

Concept. Yet requires detailed optimization.
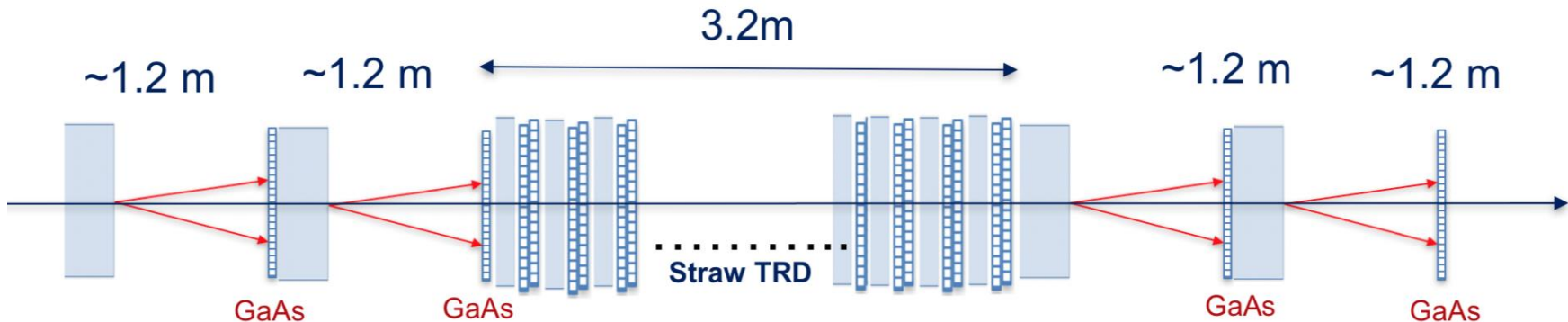
Note : Measurement of π/K/p <u>spectra</u> does not require perfect separation.
But « better is better » especialy for S:B in e.g. $D^0 -> \pi+K-$

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.
Neutrals at 0° between pipes

Acceptances need to be calculated for realistic design.

Potentially:

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

Very forward charm and beauty also measured with single leading e and μ
Leptons can be identified (how well? Background from fakes?)

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

$\gamma c\tau$ (π) = 139 km at 2.5 TeV !   **But abundant and - > forward HE μ-neutrinos! (FASER)**
$\gamma c\tau$ (K+) = 18.5 km at 2.5 TeV !

A Very Forward Hadron Spectrometer for the LHC and Cosmic Ray Physics

Short write-up

Michael Albrow[*][†]

Fermi National Accelerator Laboratory, Batavia, IL 60510, USA.
ORCID 0000-0001-7329-4925
E-mail: albrow@fnal.gov

Charged hadron production in hadron-hadron collisions with longitudinal momentum fraction Feynman-x, x_F, between 0.1 and 0.9 has not been measured above $\sqrt{s} = 63$ GeV at the CERN Intersecting Storage Rings. I discuss a way to measure this at the Large Hadron Collider at $\sqrt{s} = 13$ TeV, which is 40,000 times higher in equivalent fixed target energy, and important for understanding cosmic ray showers.

2nd World Summit: Exploring the Dark Side of the Universe
25-29 June, 2018
University of Antilles, Pointe-Ãă-Pitre, Guadeloupe, France

Job List – How can we make it happen?

New collaboration : Independent experiment at an existing collision point
→ More likely homes of **LHCb** and/or **ALICE** :
Physics synergy and eventual collaboration possible.

GOAL for discussion:
Studies towards a Letter of Intent → Proposal to LHCC:
Need collaborators to develop project – areas of interest?
Need **CERN contributions** – Vacuum pipe, infrastructure, beam conditions etc.
Physics, hardware, computing - including Monte Carlo simulations, theory, …
Develop physics case (SM, Beyond SM including DM, Cosmic rays, astrophysics,…

Housekeeping:
Set up Web site, Twiki page/repository of papers etc, Indico for meetings, etc.

Initial designs: TRDs (include tracking), calorimetry, muon chambers, trigger, DAQ

Initial estimates of « who does what », costs and timescale

Summary

Terra Incognita : large phase space (in x_F, p_T) unexplored from $\sqrt{s}$ = 63 – 14,000 GeV !
Justification in itself, but …
Need to understand **Strong Interaction** in non-perturbative sector
Important to understand **UHE cosmic rays** : Sampled shower → primary, UHE collisions, muons

Exist: Spectrometer magnets and 85m vacuum chamber + 50m 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 being developed
Open & accessible & small so evolution of techniques natural.

How and where?
Downstream of (**ALICE**) has good conditions and alignment with physics (pp + pO + OO).
Downstream of – **LHCb** – forward but not _this_ forward.
Both should find addition of VFHS enhances their physics program, both pp and nuclei
Strategically: **Independent new** experiment (allowing for later merger)
TRD experts are developing suitable TR detectors
　　　　[Crystal channeling experts are developing Xtals – could extend x_F range]

It can be done and it should be done!

Can you join or do you know someone who can?
Leadership especially needed!

Thank You

Back Ups →