A Very Forward Hadron Spectrometer for the LHC. (Expression of Interest: Snowmass EF05,EF06)

Mike Albrow, Fermilab

Take this forward! Let's write a White Paper for Snowmass 2022

Needs a LEADER or co-leaders to coordinate this (and run with the ball!)

Workshop on Forward Physics at LHC 14-15 December 2012

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Abstract

We are developing an proposal to measure at the LHC the spectra at high Feynman $x_F = p_z/p_{beam}$ of charged hadrons, light nuclei and antinuclei ($\bar{d}$, ${}^3\bar{H}$, ${}^3\bar{H}e$), as well as decaying neutrals such as K^0, Λ^0, and charm: D^0 and Λ_c^+. Charged particles with $1 \lesssim p_z \lesssim 3$ TeV can be measured in low luminosity pp and light ion runs behind an enlarged beam pipe ($R \sim 1$ m, $L \sim 20$ m) with 96 m $< z <$ 116 m. It will also be possible to measure interactions (σ_{inel}, N_{ch}) of multi-TeV hadrons on hydrogen and carbon targets.

Invited (by Michael Schmitt) to write a White Paper
For Snowmass EF06~ March 2022

Same region 80 m < z < 120 m
as **FACET** (Hale Sert's talk yesterday)
but that is for weak LLPs –
This is for strongly interacting hadrons
through beam pipe hole in dipole.

Needs hadron ID in TeV region:
Transition Radiation Detectors (~ 3 m in z)
being developed by A.Romaniouk group (ATLAS)

Not included in FACET ("off the shelf detectors")

Cross sections high (SI) so mostly
Low luminosity pp collisions (non-perturbative QCD)
Heavy ion and p-A collisions

ALICE? (already has big pipe - new back window?
or with **ATLAS**? CMS? **LHCb**?
Or new collaboration: **"FORWARD"**

Forward Hadron Spectrometer for LHC

A new subsystem for an existing central experiment
Or a new collaboration / ~ independent
80– 125m downstream of any IR

From

Forward Spectrometer meeting

16–17 Apr 2020
CERN

A) Charged and neutral TeV hadron production spectra in p + p, p + O, O + O low pileup short runs.

Read out with full central detectors

35 Tm spectrometer magnet D1 (will be) already there

Large region of unexplored phase space above √s = 63 GeV !

Identified charged hadrons with [0.05 < $x_F = p_z/p_{beam}$ < 0.9] not measured at LHC

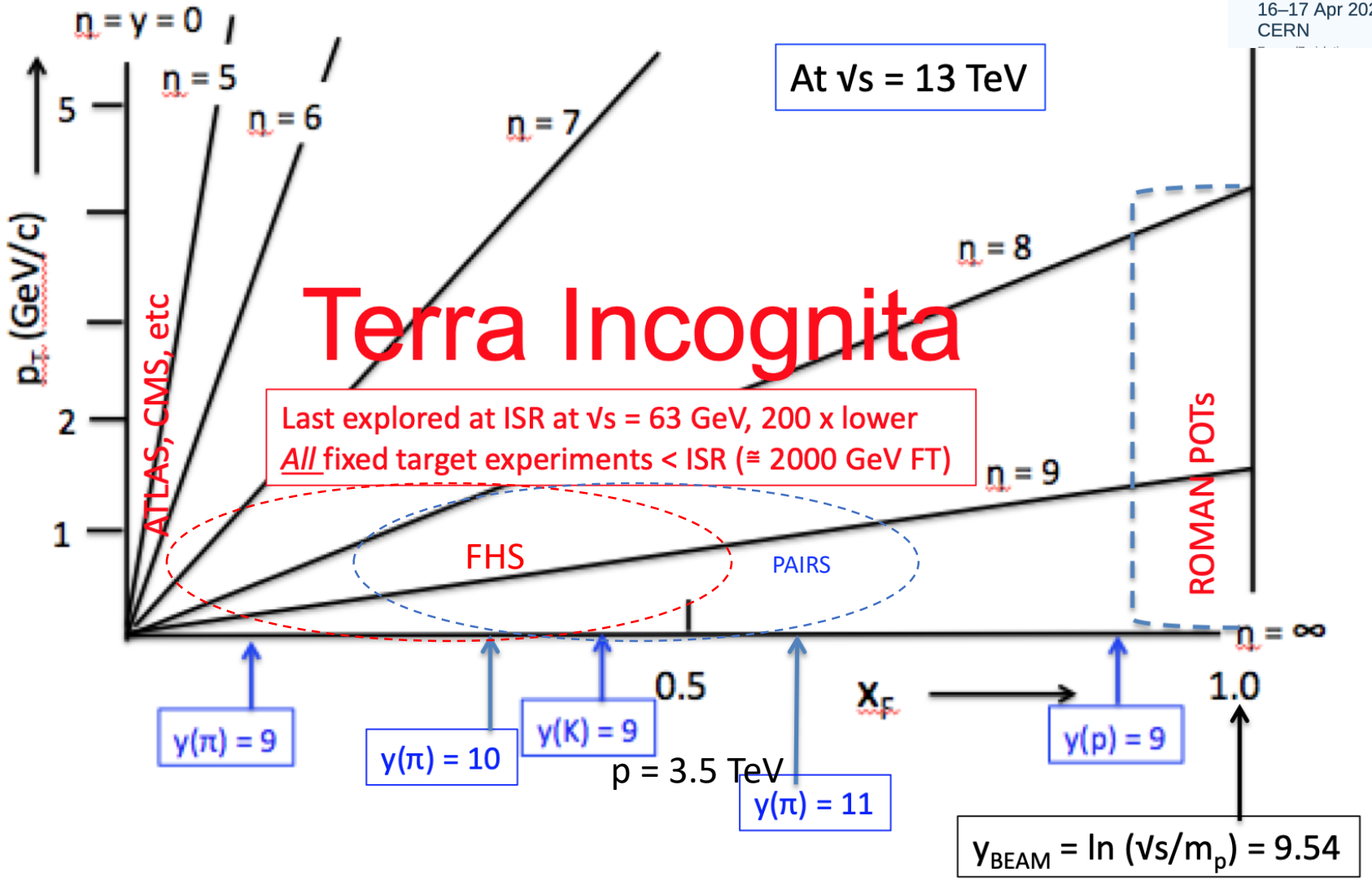
Also pairs e.g. D^0 --> $K^{\pm}$ $\pi^{\pm}$ and Λ^0 --> p π and $\mu^+\mu^-$ etc.

Must be done at LHC before the end! Real estate is there: **80 m < z < 120 m**

From

Forward Spectrometer meeting

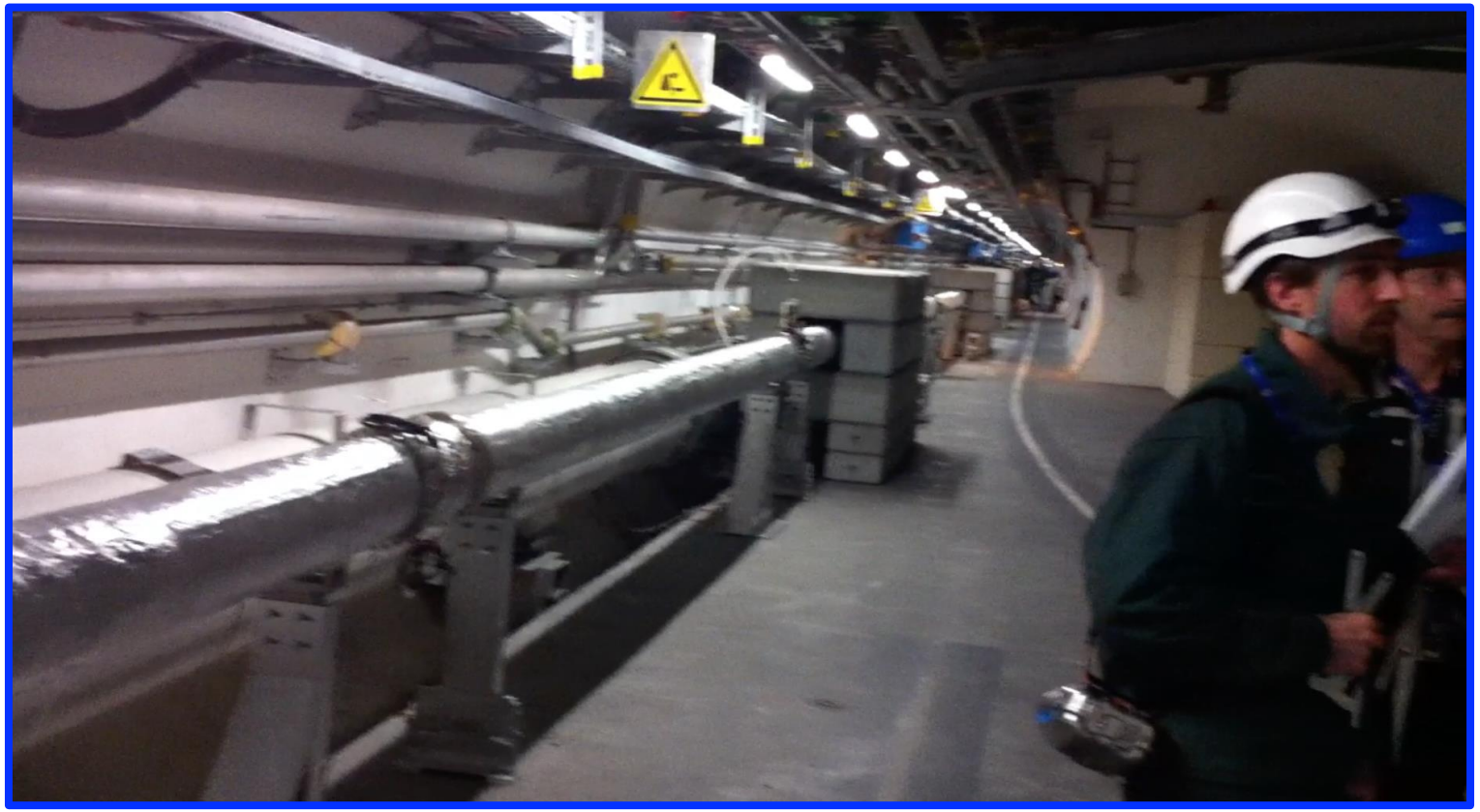
16–17 Apr 2020
CERN



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

Region looking **along LHC tunnel**, beam separation dipoles & CMS way behind me.
20 cm diameter straight pipe with both beams for 50 m. (Cladding)
Make this pipe larger diameter: 20 cm – 60 cm

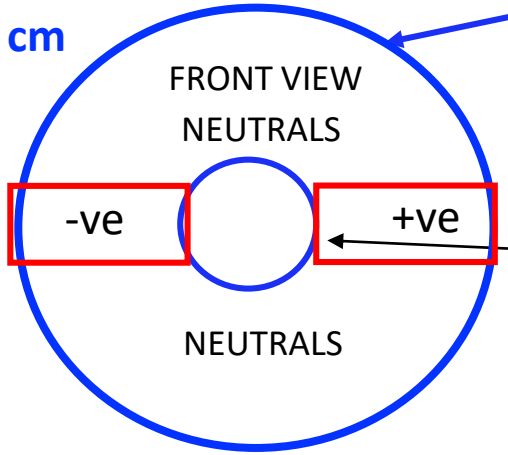
Vincent Baglin's talk



TOP (BENDING) VIEW

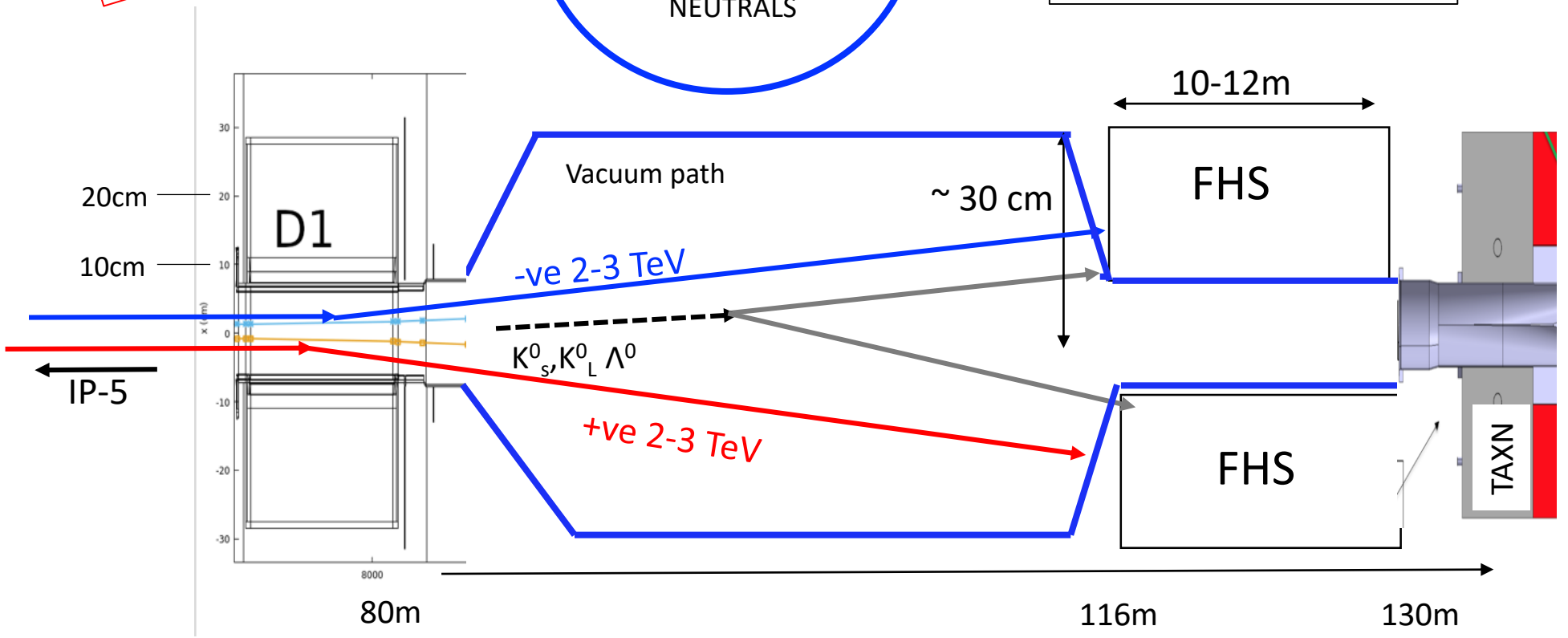
Big pipe radius R ~ 50 cm

SCHEMATIC – Pipe dimensions TBD



Large pipe cross section R ~ 50 cm and back window area 0.5 m^2
Transition at z ~ 116m

Outgoing beam pipe R ~ 10 cm (Split inside TAXN)



FHS as a Multi-particle Spectrometer

Acceptance for 2 or more particles from same event. (If pile-up, timing can help)
Positive and negative particles on R & L sides of pipe, near horizontal plane.

Acceptances calculated by Marta Sabate-Gilarte for some channels …
Details will need to be calculated for real design of system – and backgrounds

Potentially:

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

Very forward charm and beauty also inferred from single leading e or μ
Leptons can be identified : Track + EM calorimeter & muon chambers behind HCAL

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

$\gamma c\tau\,(\pi)$ = 139 km at 2.5 TeV ! **But abundant and - > forward HE μ-neutrinos! (FASERν)**
$\gamma c\tau\,(K^+)$ = 18.5 km at 2.5 TeV !
$\gamma c\tau\,(D^0)$ = 16.5 cm at 2.5 TeV !

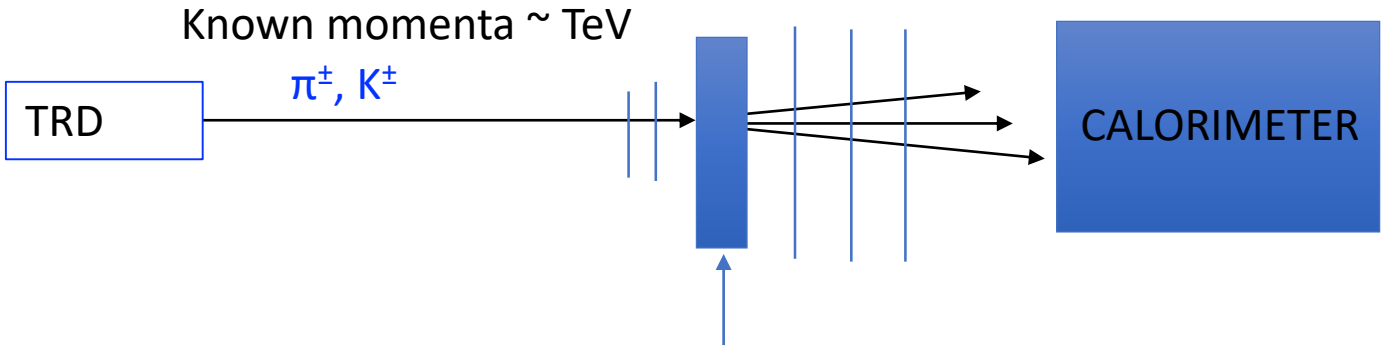
ANOTHER POTENTIAL USE OF FHS:

Inelastic (& elastic?) cross sections of multi-TeV $\pi^{\pm}$, $K^{\pm}$, etc.

Forward Spectrometer meeting

16–17 Apr 2020
CERN

IDEA:
Behind TRD-Tracker have multi-TeV identified $\pi^{\pm}$, $K^{\pm}$
Can put in front of calorimeter a thin target followed by short tracker:



Very simple addition:
σ_{inel}, N_{ch}, σ_{el},

Forward Hadron Spectrometers : Possible contents of Snowmass White Paper (March 2022)

Contents

For LLP not this

The **Forward Physics Facility** FPF is very different: penetrating particles (LLPs, ν, etc.) so weakly interacting, z > 600 m in new hall.

This could be a "**Nearer Forward Physics Facility**": strongly interacting partlcles, QCD COMPLEMENTARY. Z = 80 – 120 m
but another place for ν physics too? (emulsions behind 300 λ_{INT} Fe)
"Small experiments with small (new) collaborations"?
No civil engineering needed ? But Hot area!

Experiments in FPF might want also a "near detector" (cf ν experiments)

Leadership opportunity!

I am busy with FACET LOI preparation & Snowmass WP for LLPs – also “retired”

Would one or two of you like to lead or co-lead the preparation of a White Paper (and beyond?)

- draft White Paper by March-April, final version June (?)
- Short meeting/workshop in Spring?

This is not specific to CMS : can be at any of 4 collision points.

Alice already has a big pipe – upgrade to allow this? Beyond ARP in ATLAS?? LHCb? CMS opposite side to FACET?

This could lead to a major program – **the low-Q^2 frontier of QCD** is rich in unknown physics

Forward Spectrometer meeting

16–17 Apr 2020
CERN

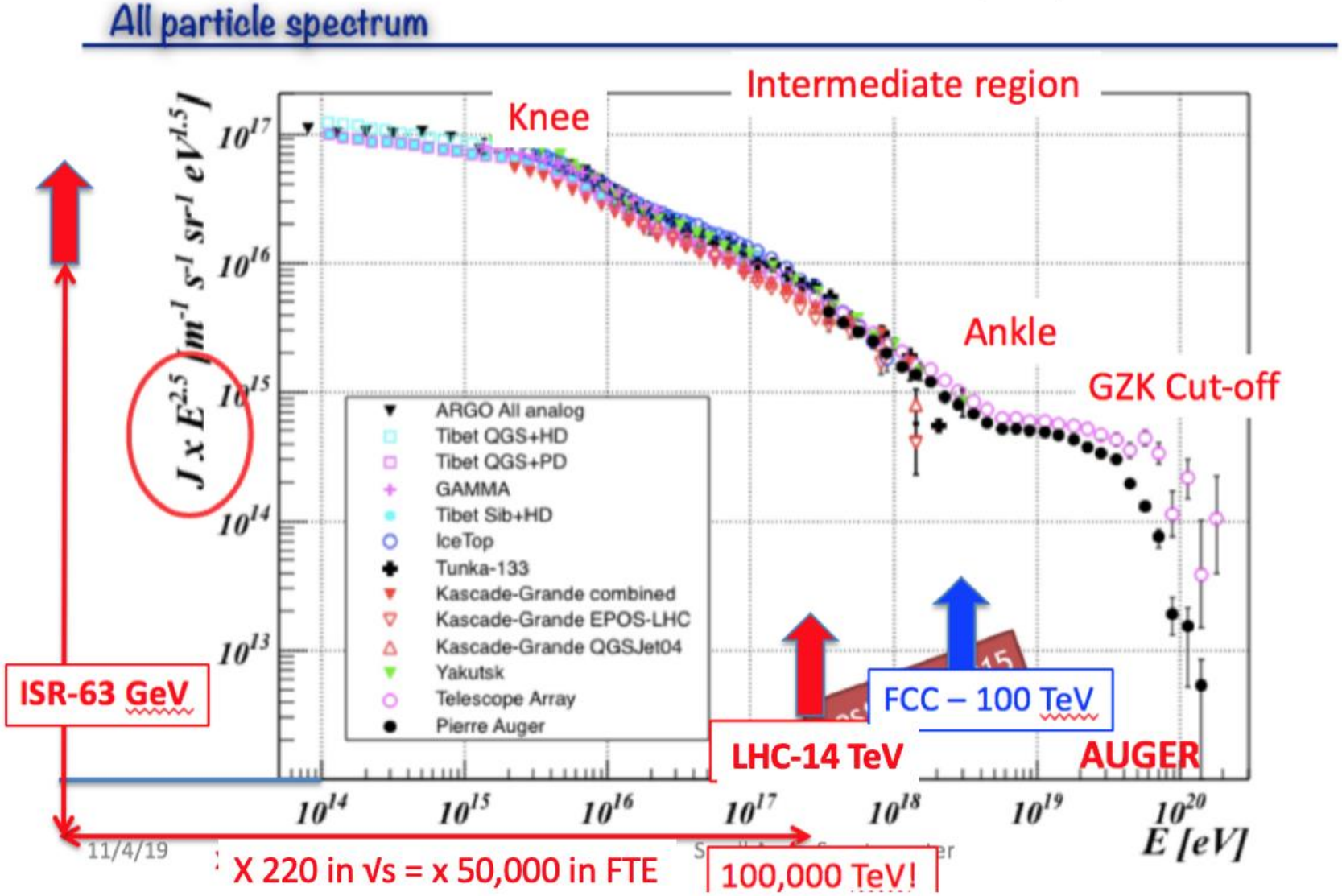
https://indico.cern.ch/event/868473/

	Beam pipe issues — *CERN*	*Vincent Baglin* — 14:30 - 15:00
15:00	**Introduction to Mode A: Hadron spectra** — *CERN*	*Michael Albrow* — 15:00 - 15:30
	Particle spectra, acceptances — *CERN*	*Marta Sabate Gilarte* — 15:30 - 16:00
16:00	**Transition Radiation Detectors for hadron ID** — *CERN*	*Michael Cherry et al.* — 16:00 - 16:30
	Cosmic ray showers & Forward hadrons — *CERN*	*Dr Tanguy Pierog* — 16:30 - 17:00
17:00	**Way forward, plans** — *CERN*	*Mike Albrow, all* — 17:00 - 17:20
	Next LHC forward physics meetings — *CERN*	*Christophe Royon et al.* — 17:20 - 17:30

THANK YOU : DISCUSS!

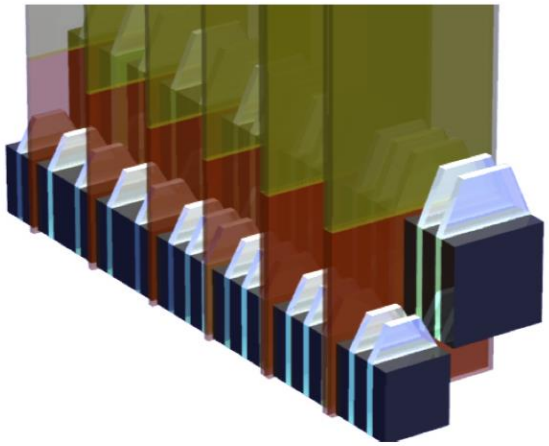
Some additional slides -->

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

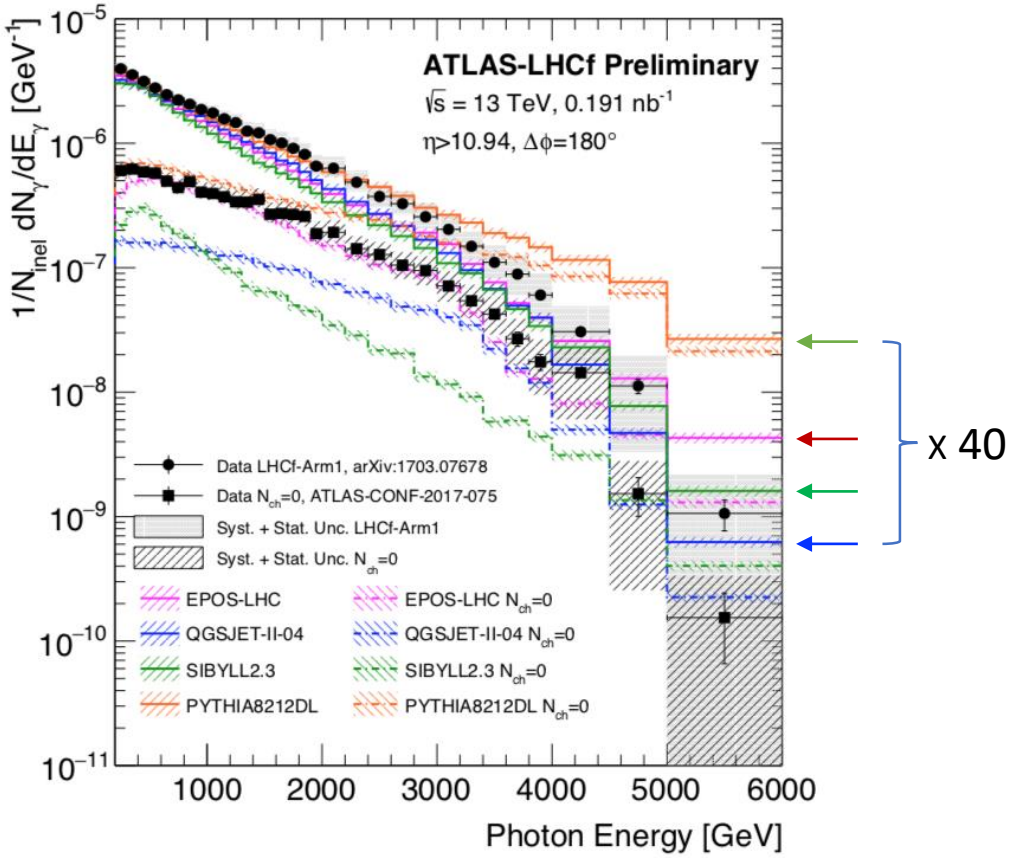


LHCf is a small 0° calorimeter measuring photon-like and n-like showers
Only 1.6 λ_I and 4 cm in size, $\sigma(E)/E$ ~ 40% for neutrons.
Low-PU, High β^* runs

Huge spread in predictions
Tanguy Pierog's talk:



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



ZDC in CMS
7 λ_I and 8cm x 10 cm
Must be smaller for Run 4
-include it for low-PU runs

With FMS we can measure spectra small p_T & up to p_z ~ 3 TeV
of charged : π, K, p, d, t, (and anti-d,t) – μ
and neutral : π, K, ρ, φ, n, Λ, …. & D^0 → K- π (some acceptance)

ACCEPTANCE STUDIES being done

PHYSICS GOALS for L&R Charged particles (not complete!)

deuterons, tritons

Precise measurements of Feynman-x (x_F) spectra at small p_T (< ~2 GeV) of:

$\pi+, \pi-, K+, K-, p, \bar{p}, d, \bar{d}, t, \bar{t}$, … possibly $K^0_s \rightarrow \pi+\pi-$, $\Lambda^0 \rightarrow p\pi$ (acceptance under study).

In p+p and p+O and O+O collisions (for cosmic ray showers in atmosphere)

Tanguy Pierog's talk

Intrinsic charm: p = {uudcc} giving leading $D^0 \rightarrow K^+\pi^-$ & $K^-\pi^+$

Full reconstruction challenging but → forward muons

Other reconstruct-able particles: $J/\psi \rightarrow \mu^+\mu^-$ (6%) ; $\Upsilon(1S) \rightarrow \mu^+\mu^-$ (2.5%)

These are 'intrinsically' important + to understand **μ and ν in cosmic ray showers.**

Energy Frontier and Cosmic Frontier are two US-HEP priorities!

CAVEAT: Acceptance for 2-particle states still to be calculated

Production of light nuclei and **antinuclei – antiprotons, antideuterons, antitritons**, $\bar{He}^3$

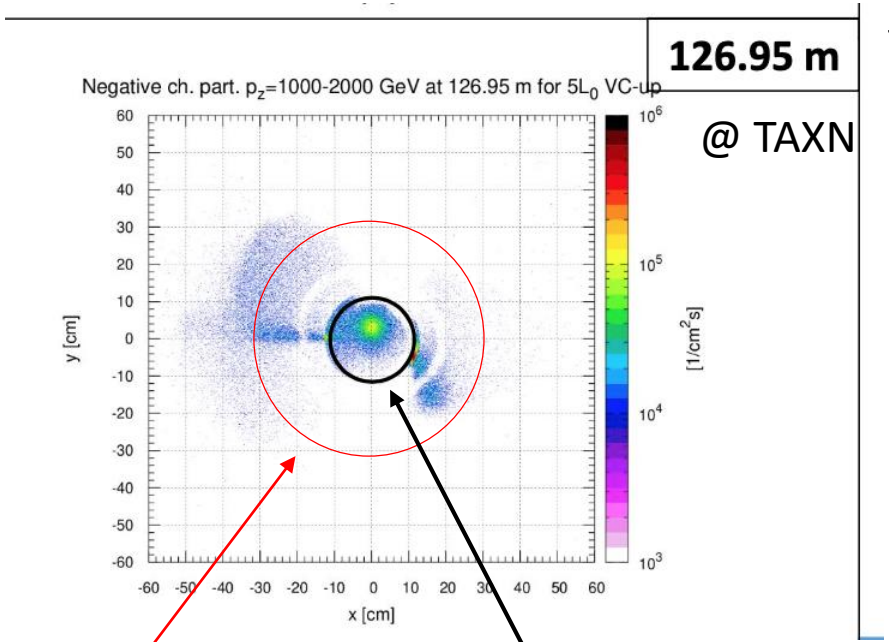
Needed to understand background to Galactic Center γ-ray excess (Dark Matter Annihilation?)

Diffraction dissociation – products, e.g. p → n π+, p (π+ π-), Λ^0 K^+

Low Q^2 frontier of QCD needs further understanding.

Marta Sabate Gilarte's talk

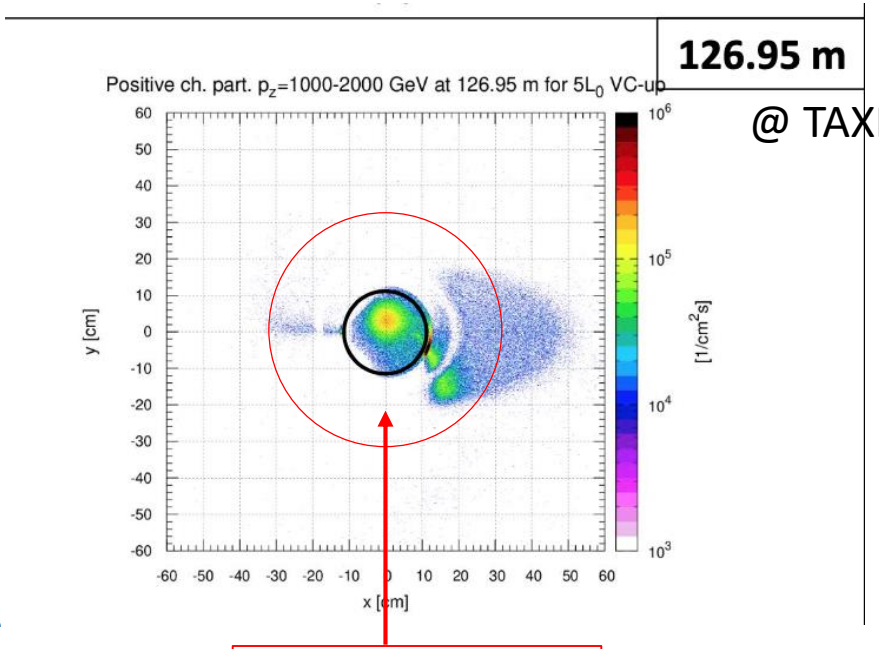
NEGATIVE particles 1 – 2 TeV (through D1 aperture)



R_{outer} (at 116m) = 30 cm
η = 6.65

R_{inner} (at 116m) = 10 cm
η = 7.75

POSITIVE particles 1 - 2 TeV (through D1 aperture)



No primary charged
Particles UP & DOWN

HADRON spectroscopy in L&R quadrants in low pile-up short runs (Mode A)

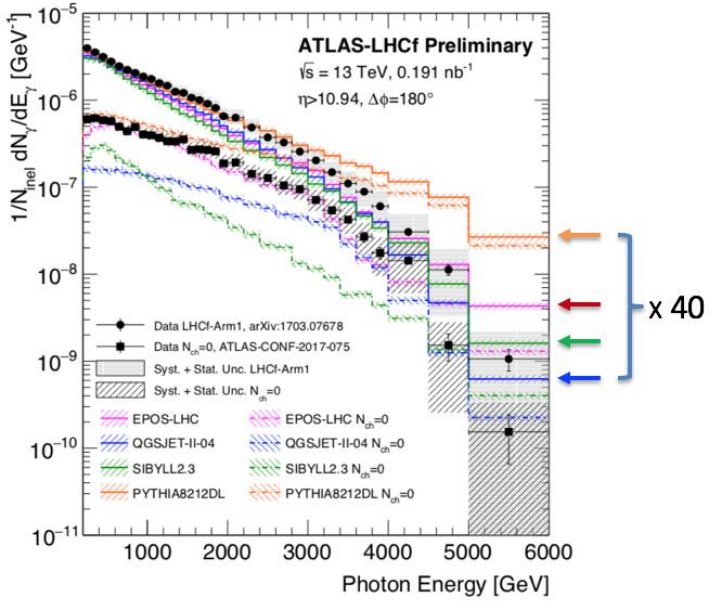
Implications for the FCC = Future CERN Colliders
100 TeV pp and heavy ion colliders FCC

Designing such machines requires advanced knowledge of very forward very energetic particles.
Beam particles hitting pipes and collimators etc.
Also particles produced in the collisions – all x_F (tens of TeV) and small angles (p_T)

Not only protons (dominant at high x_F) and neutrons but also pions, kaons, etc.

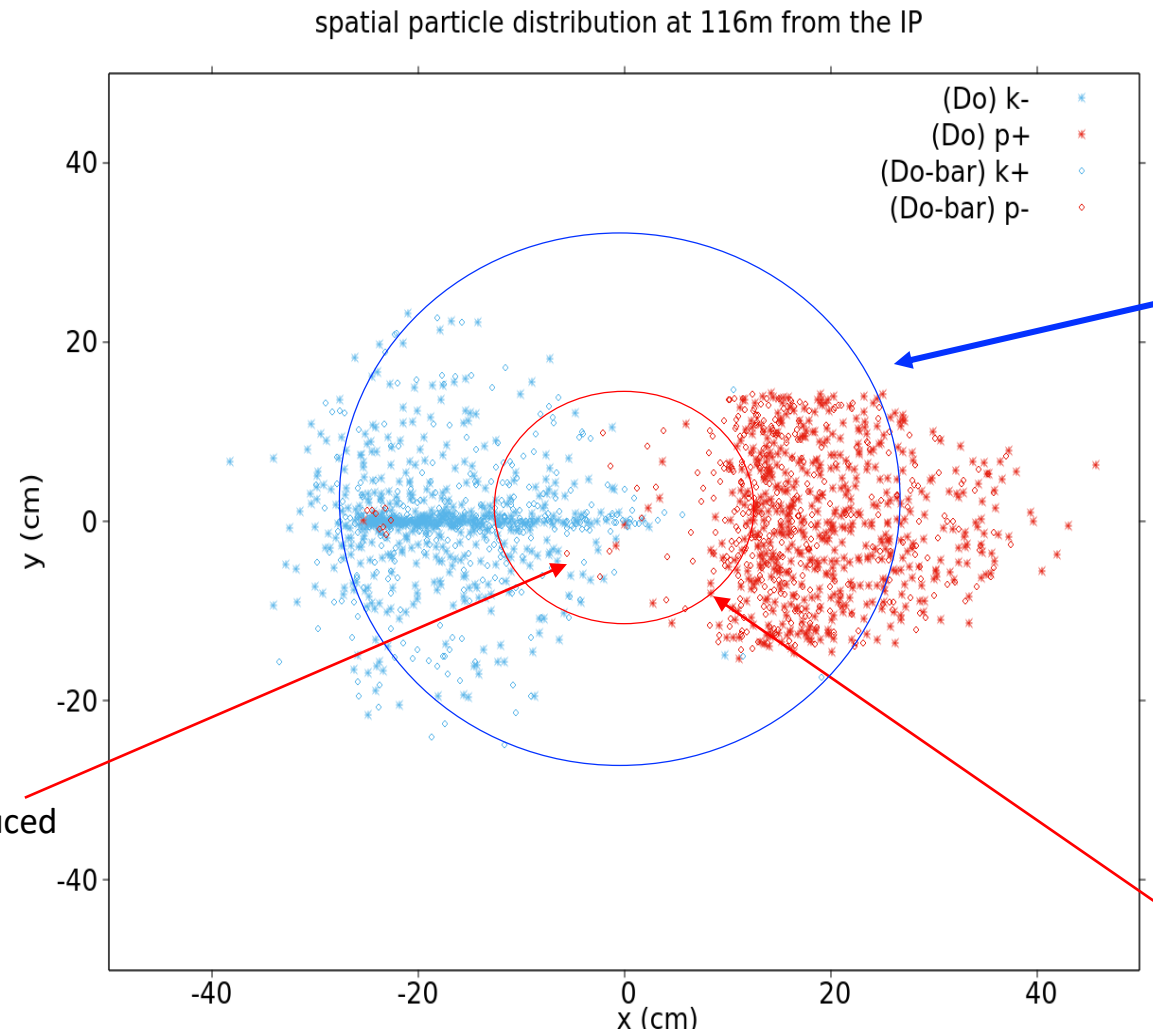
We need these spectra, presently very uncertain!

So FCC will be a service to CERN's future FCC!



Marta Sabate Gilarte's talk

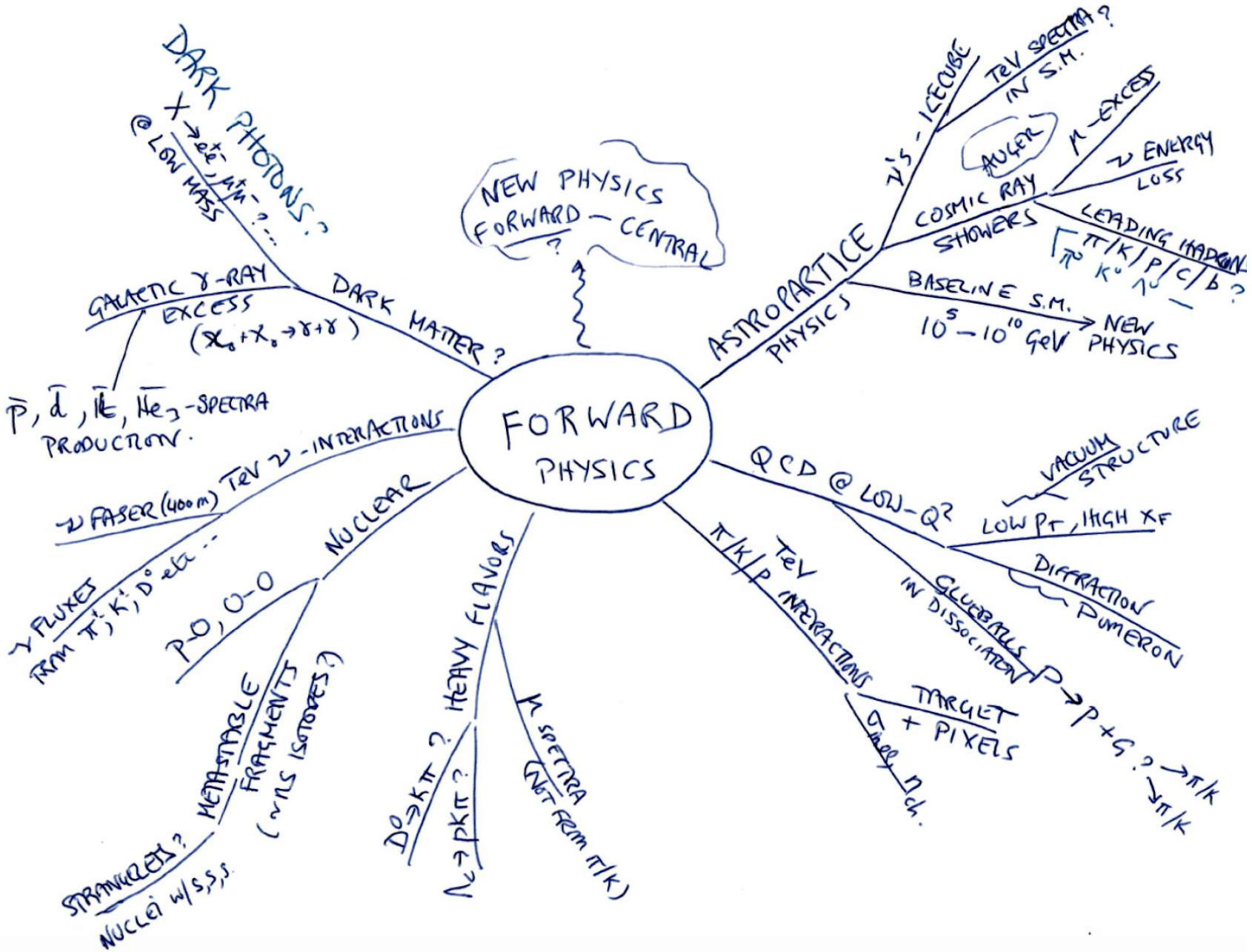
We can measure $D^0 \rightarrow K^+ \pi^-$? Plot from Marta Gilarte (CERN)



Back big pipe
Thin window
R ~ 30 cm

Outgoing with reduced
Height if possible

Outgoing pipe
R ~ 12 cm


FORWARD PHYSICS
NEW PHYSICS FORWARD – CENTRAL ?
DARK MATTER ?
DARK PHOTONS ?
@ LOW MASS
GALACTIC γ-RAY EXCESS
$\bar{p}, \bar{d}, \overline{He}, \overline{He_3}$ - SPECTRA PRODUCTION.
ASTROPARTICE PHYSICS
ν's - ICECUBE
TeV SPECTRA ? IN S.M.
AUGER
COSMIC RAY SHOWERS
μ - EXCESS
ν ENERGY LOSS
LEADING HADRON
BASELINE S.M. $10^5 - 10^{10}$ GeV NEW PHYSICS
QCD @ LOW-Q?
VACUUM STRUCTURE
LOW P_T, HIGH X_F
DIFFRACTION
PUMERON
GLUEBALLS IN DISSOCIATION
$\pi/K/p$ TeV INTERACTIONS
TARGET + PIXELS
σ_{inel}, n_{ch}.
HEAVY FLAVORS
$D^0 \to K\pi$?
$\Lambda_c \to pK\pi$?
μ SPECTRA (NOT FROM π/K)
NUCLEAR
p-O, O-O
METASTABLE FRAGMENTS (~ALL ISOTOPES?)
STRANGELETS ?
NUCLEI w/ s,s,s
ν FLUXES FROM $\pi^\pm, K^\pm, D^0$ etc...
ν FASER (400 m) TeV ν - INTERACTIONS