Forward Multiparticle Spectrometer for LHC

A new subsystem for CMS Run 4 (HL-LHC)
80– 125m downstream of IR-5 (IR-1 option)

BUY ONE, GET ONE FREE!

Two operational modes:

TODAY

A) Charged and neutral TeV hadron production spectra
in p + p, p + O, O + O low pileup short runs.
Read out with full CMS detectors
35 Tm spectrometer magnet D1 (will be) already there!

SMP-HAD 03.20
Guaranteed physics in unexpored phase space

B) Search for new light long-lived decaying neutrals
in p + p at high luminosity (LLPs or WILPs)
Independent trigger & read out

YESTERDAY

EXO – LLP 03.27
BSM discovery potential

Steel absorber and 35 Tm sweeping magnet D1 (will be) already there!

Two half-day meetings on Forward Multiparticle Spectrometer April 16+17 2020

Purpose: present and discuss ideas. Critique and distinguish possible and not possible

Plan next level of studies and especially who will contribute to a write-up / note /doc

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Friday 17th: Mainly measurement of very forward hadrons in pp, pO, OO at low luminosity

14:30	**Beam pipe issues** — CERN Considerations of a long, large diameter beam pipe	*Vincent Baglin*, CERN	14:30 - 15:00
15:00	**Introduction to Mode A: Hadron spectra** — CERN High x_F low-p_T region – uncharted territory since ISR. Including charm and antinuclei	*Michael Albrow*	15:00 - 15:30
	Particle spectra, acceptances — CERN Tracking through Q1-Q3 and D1 magnets – through big pipe to detectors	*Marta Sabate Gilarte*, CERN	15:30 - 16:00
16:00	**Transition Radiation Detectors for hadron ID** — CERN How to identify multi-TeV π / K / p ? Not Cherenkov, TRD!	*Michael Cherry et al.*	16:00 - 16:30
	Cosmic ray showers & Forward hadrons — CERN Why astroparticle physics needs these measurements	*Dr Tanguy Pierog*	16:30 - 17:00
17:00	**Way forward, plans** — CERN How to make it real? Work (workers) needed to make a NOTE or LOI or similar.	*Mike Albrow, all*	17:00 - 17:20
	Next LHC forward physics meetings — CERN	*Christophe Royon et al.*	17:20 - 17:30

FMS – Charged L&R arms - OVERVIEW

Very forward charged particle production – how to measure it

Use new superconducting **D1 dipole** (Integral B.dL = 35 Tm) as a **spectrometer magnet**.
Downstream of IR 5 as **extension of CMS** in Run 4 (2027+)

Straight section in vacuum from ~ **80 m to ~ 127 m**.
Larger beam pipe R = 30 cm (cf R = 10 cm now)
for charged particles to emerge through thin windows: + & - sides - Low pile-up only

Vincent Baglin's talk

Detectors over 10 – 12 m in front of TAXN at 127 m:

Julie Hogan's talk y'day

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

[Possible targets + tracking to study multi-TeV π, K, p, $\bar{p}$ interactions]. --- bonus!

Imaging Hadron Calorimeter for energy measurement and muon filter

Muon tracking behind calorimeter (and behind D1)

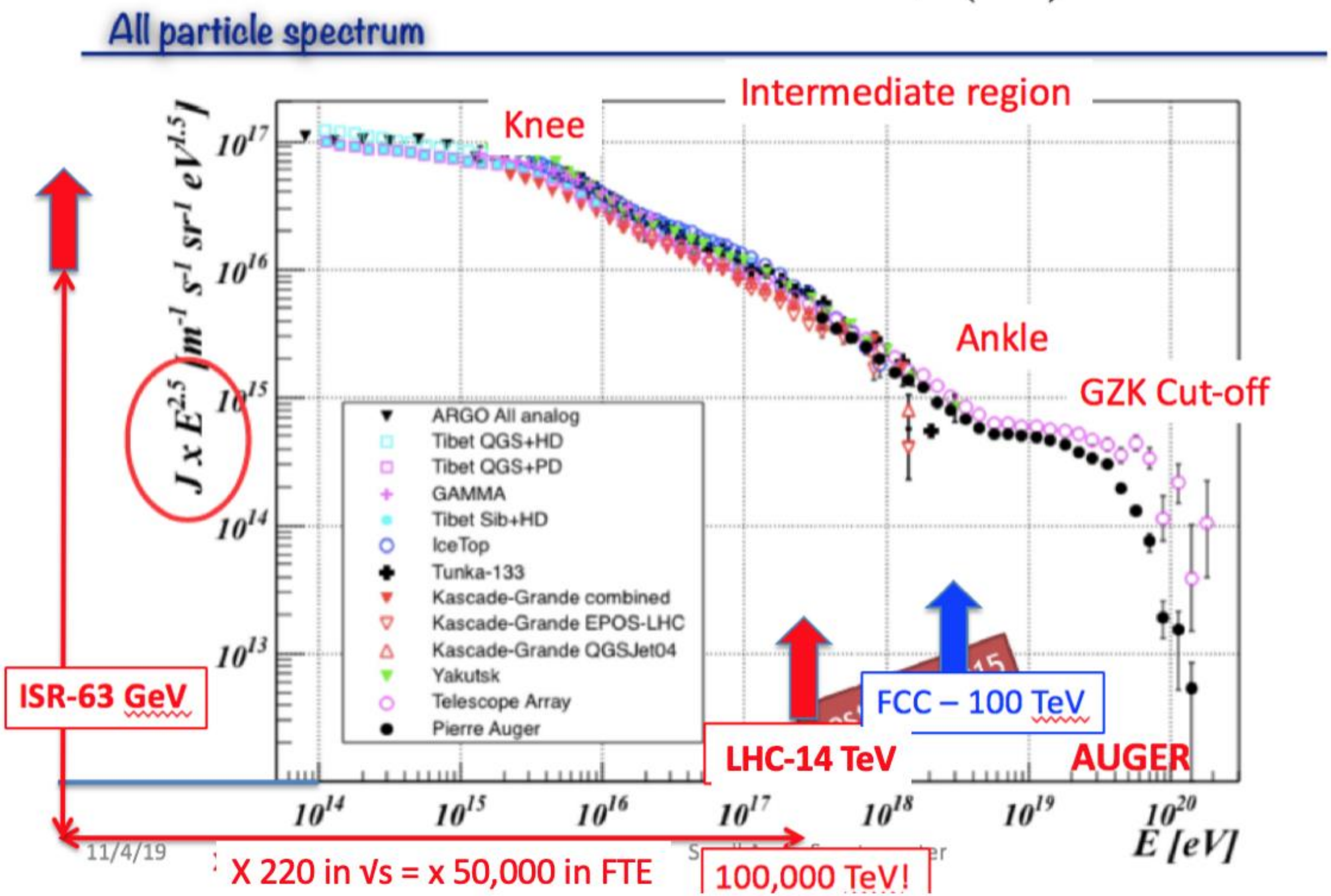
Transition Radiation Detectors for $\gamma = E/m$ in $10^3 – 3.\ 10^4$ region (novel)

As developed for CMS at HL-LHC

Mike Cherry's talk

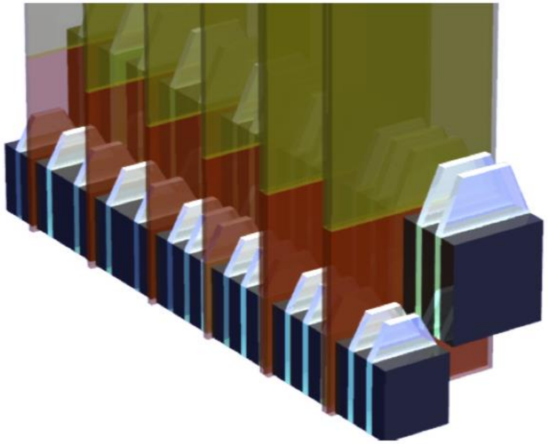
Tanguy Pierog's talk

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

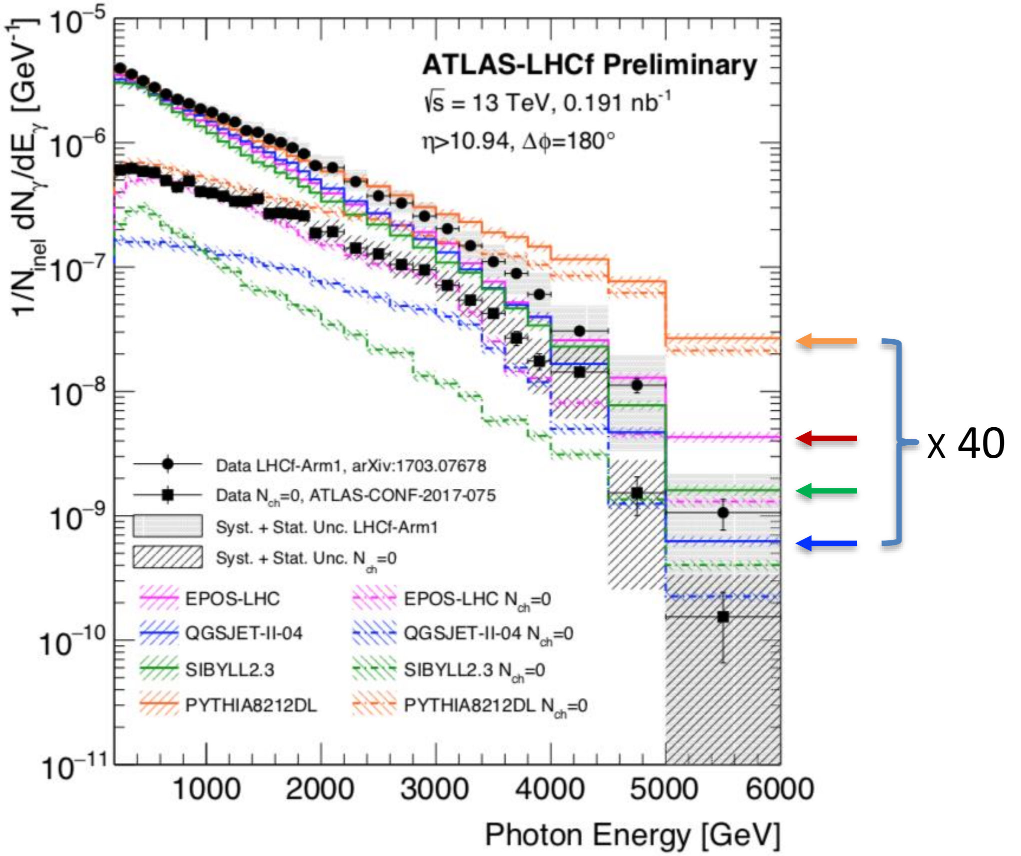


LHCf is a small 0° calorimeter measuring photon-like and n-like showers
Only 1.6 λ_I and 4 cm in size, $\sigma(E)/E$ ~ 40% for neutrons.
Low-PU, High β* runs

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, …. & $D^0 \rightarrow$ K- π (some acceptance)

ACCEPTANCE STUDIES being done

Production spectra of charged mesons at pp 13TeV

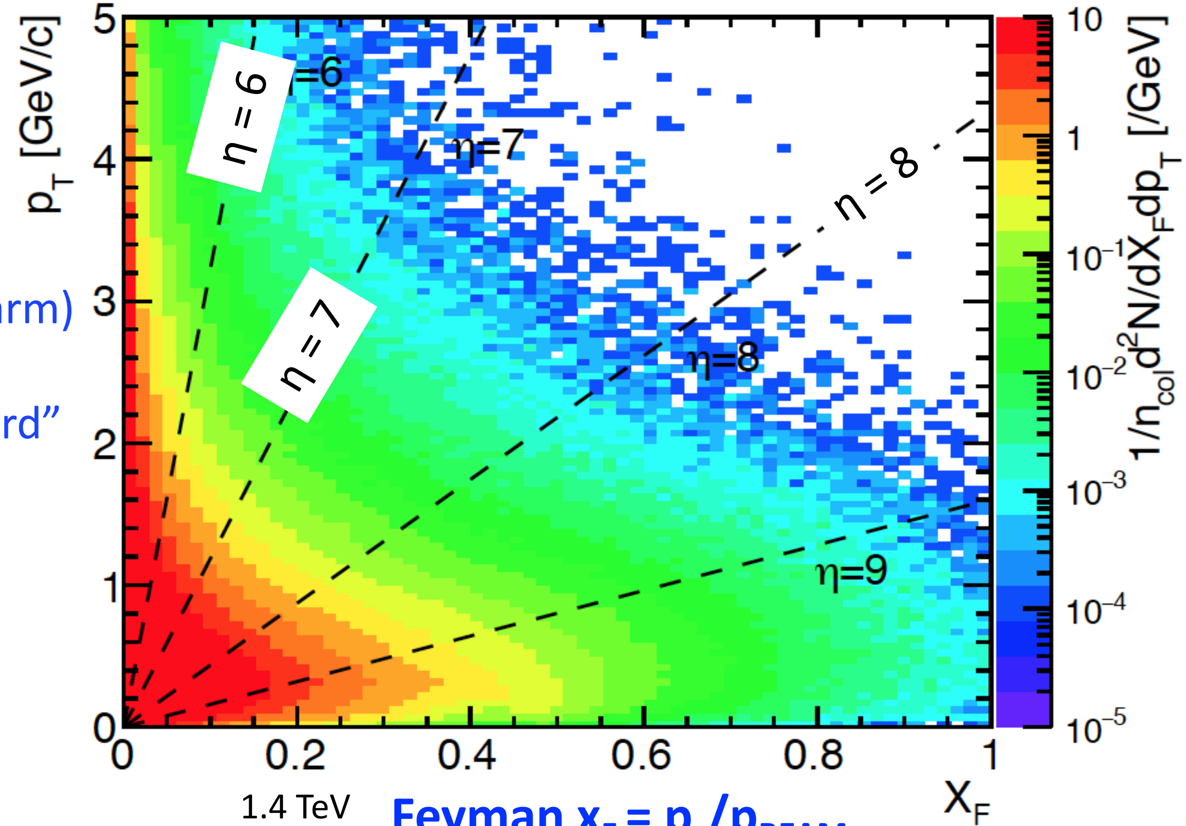
H.Menjo

(Dec 5th 2019)

- pp collisions with $\sqrt{s}$ = 13 TeV
- Event generation by CRMC for Pythia8, QGJSET2-4, EPOS-LHC, Sibyll 2.3c
- 10^7 collisions for each interaction model

EPOS-LHC

η = 4.5 (LHCb charm) is θ =1.3° but is not "very forward"

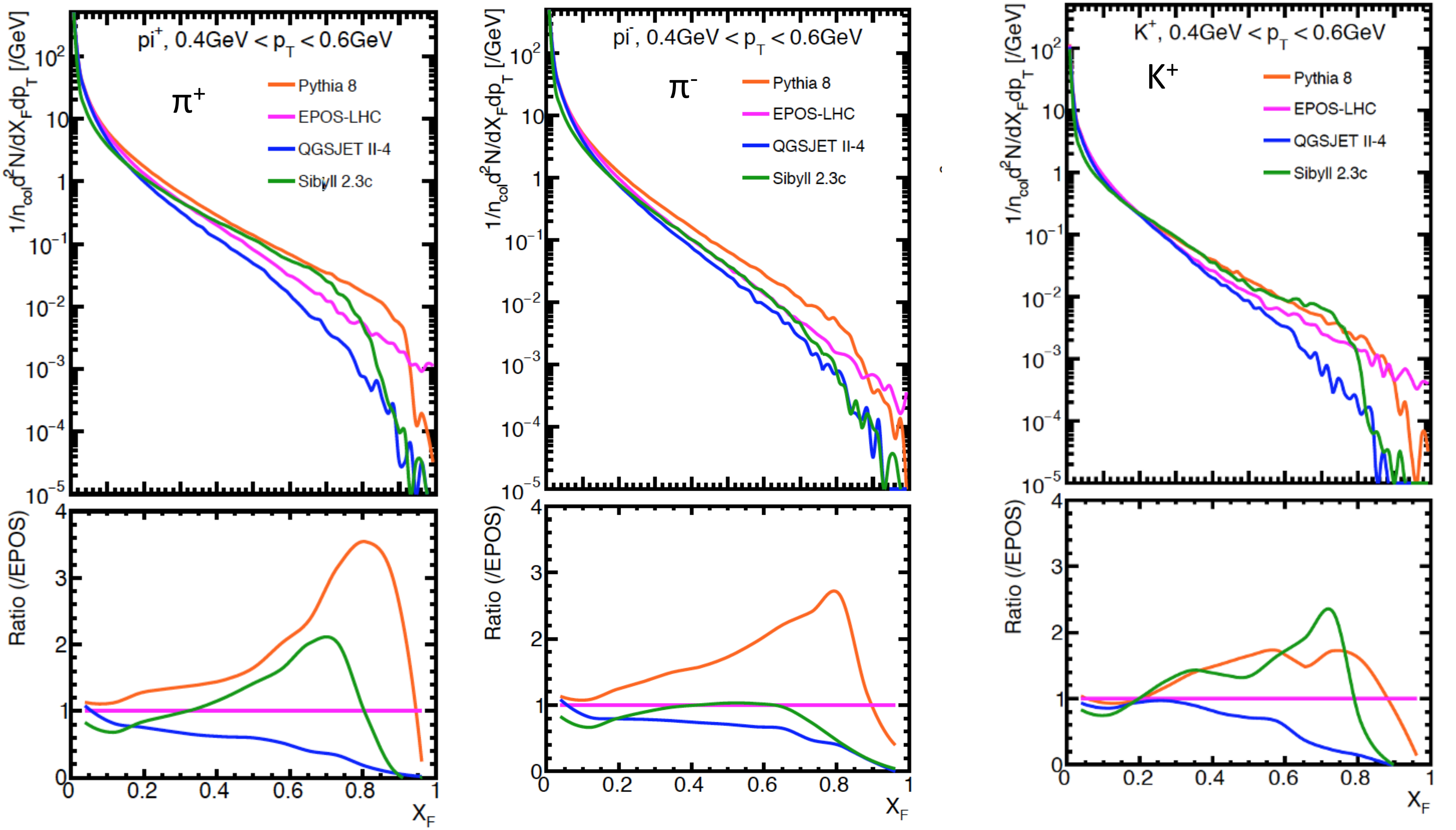


1.4 TeV **Feyman $x_F = p_z/p_{BEAM}$**

Density of charged pions in p_T, x_F. Most have p_T < 1 GeV/c and $|\eta|$ > 7 – unexplored region

TOTEM & PPS (p's at x_F > 0.9) and ZDC & LHCf measure neutrals (n + K^0_L , $\pi^0 \rightarrow \gamma\gamma$) at θ ~ 0°

Comparison of Monte Carlo generators, Low-p_T π and K (H. Menjo)



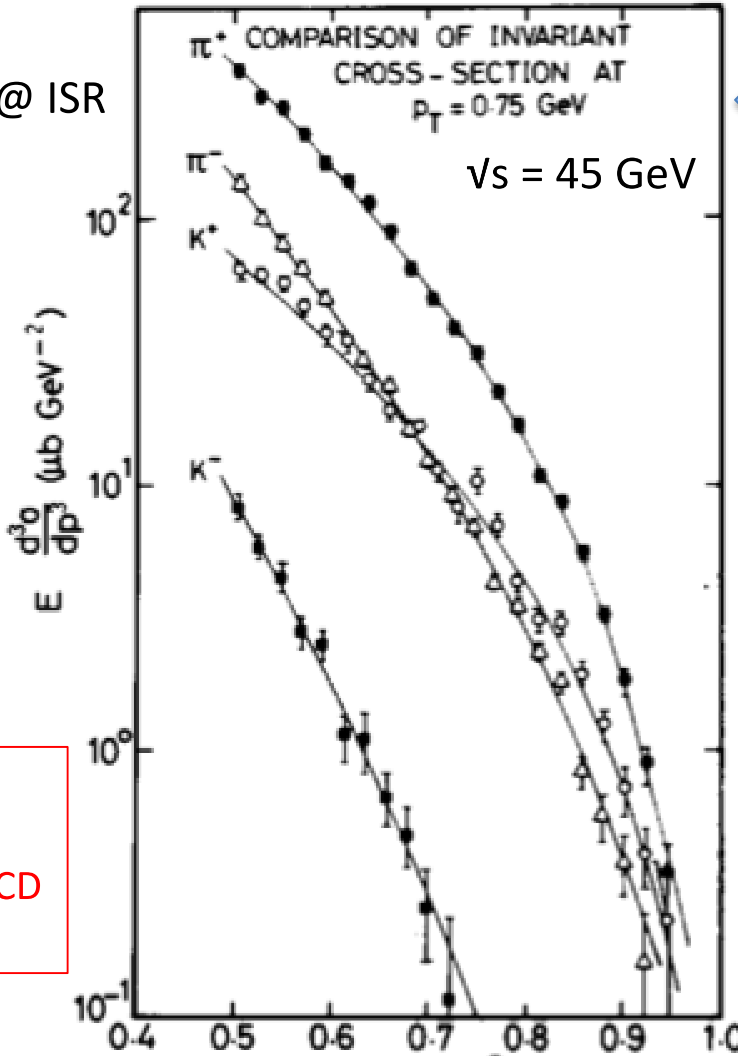
Feynman $x_F = p_z/p_{BEAM}$

(PYTHIA8: QGSJET II-4) ~ 50 at x_F = 0.8

No Data! FMS reach → ~ 0.4

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

42 years ago !



$x = \frac{2p_L}{\sqrt{s}}$

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

Valence quark counting:

π+ = u dbar. (2)
π- = ubar d. (1)
K+ = u sbar. (1)
K- = ubar s. (0)

Low mass diffraction dissociation.

Feynman scaling (1969):
Spectra fn(p_T, x_F) not √s
Non-interacting partons, not QCD
Ignores thresholds (c,b)

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.

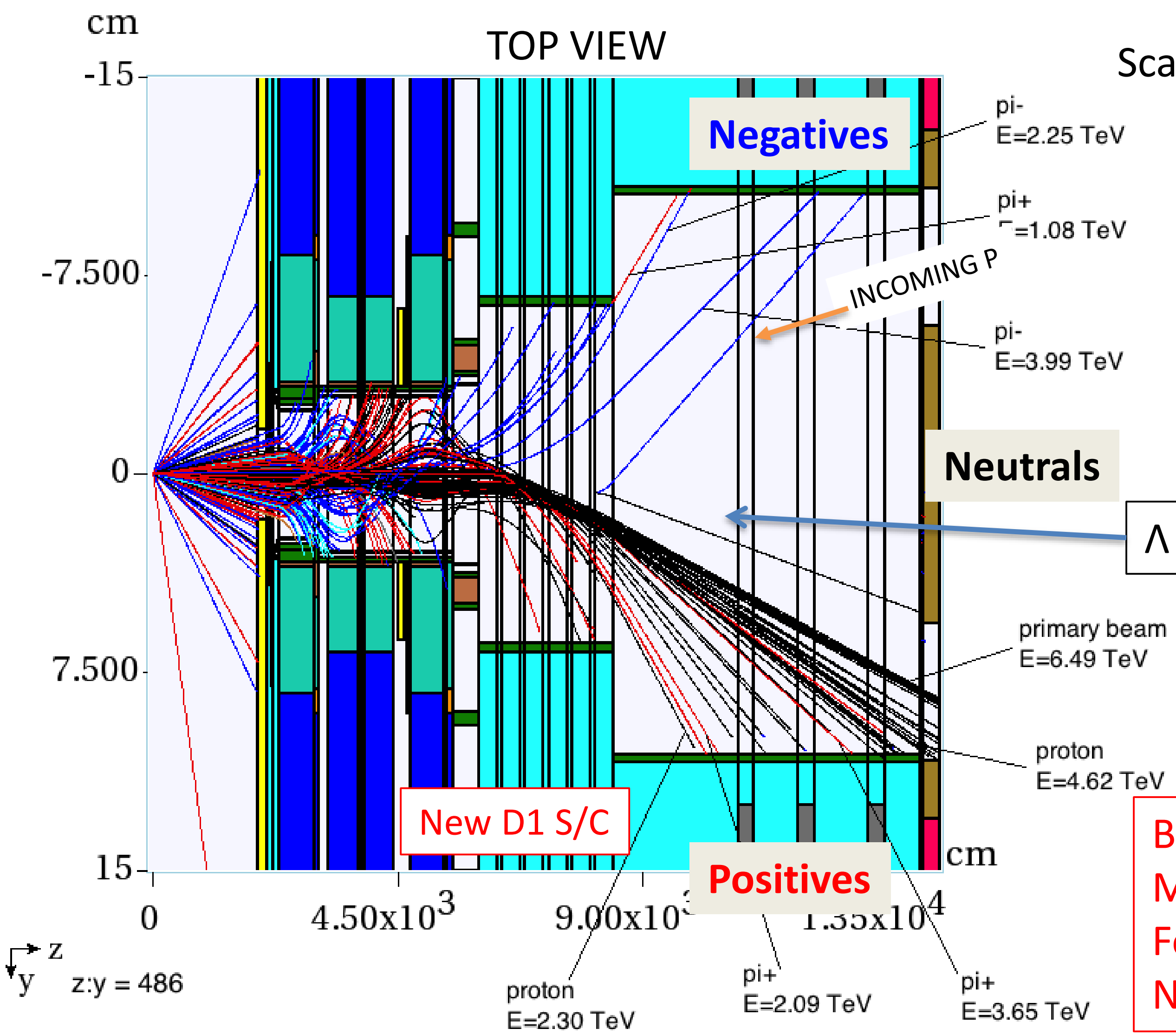
200 inelastic collisions at Pt 5 **2018 (13 TeV, β* = 0.55 m):** MARS

Nikolai Mokhov
Ottavio Fornieri

If μ = 50 this is 4 bunch crossings

Scale factor x:z = 486:1

From interaction



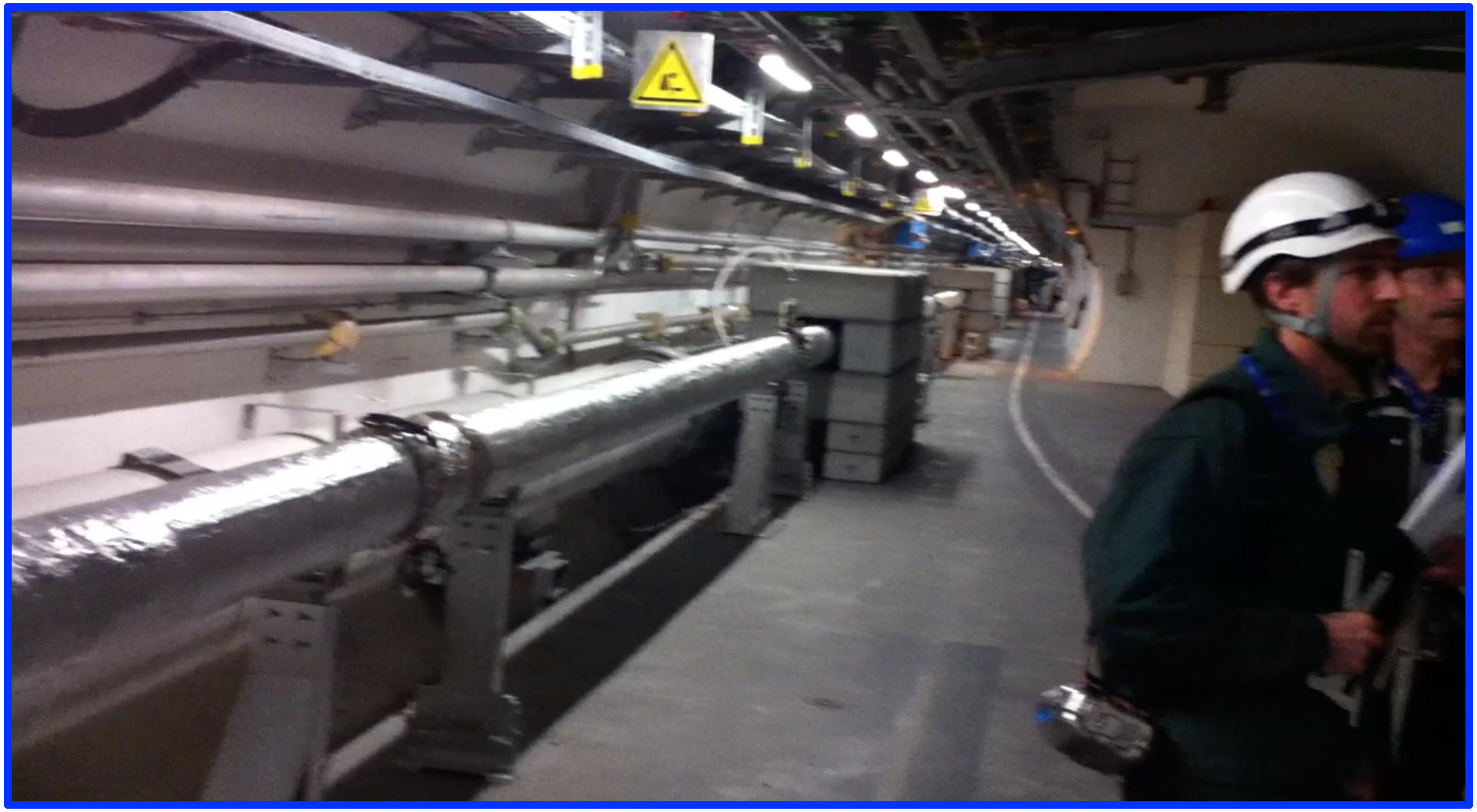
Being redone
Marta and Francesco
For 14 TeV and Run 4.
New D1, beam pipe

Hitting pipe: 0.5 π- and 1 π+ and about 2 protons / 50 collisions. Near horizontal plane

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



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**, $\overline{\mathbf{He}}^{\mathbf{3}}$
Needed to understand background to Galactic Center γ-ray excess (Dark Matter Annihilation?)

Diffraction dissociation – products, e.g. $p \rightarrow n\,\pi+$, $p\,(\pi+\,\pi-)$, $\Lambda^0 K^+$

Low Q^2 frontier of QCD needs further understanding.

DPMJET prediction (Prob. Too high)

Very uncertain! Illustration only

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

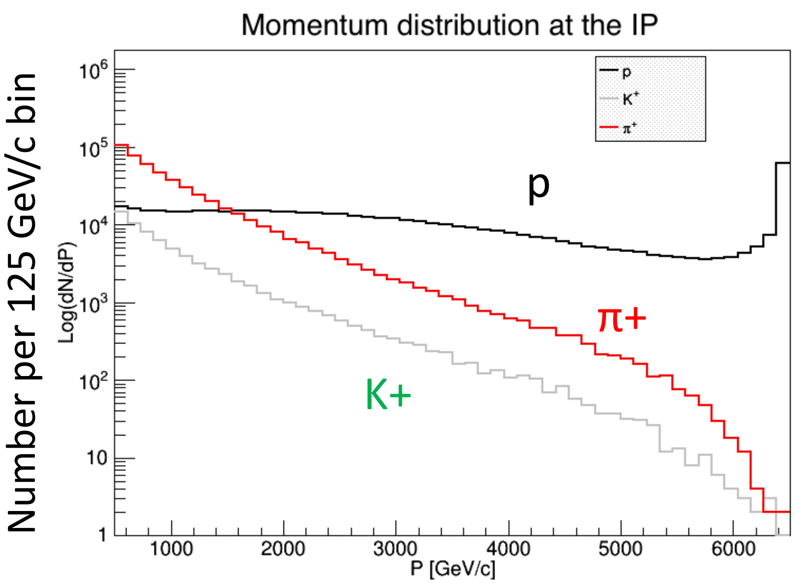
In 1 second, with 2808 bunches,
Have 30×10^6 bunch crossings and
$30 \times 10^6 \times \mu$(= interactions/X) events.

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

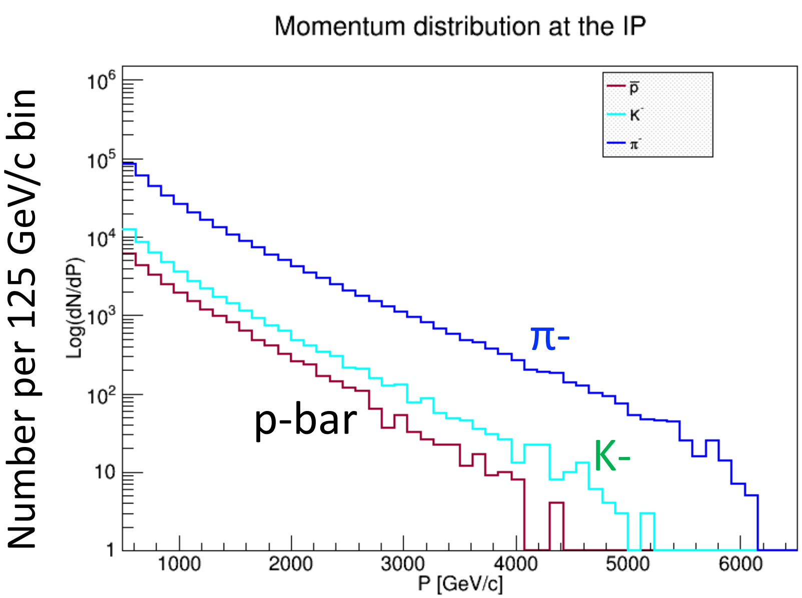
p's > π^+ above 1.5 TeV and flattish;
High x_F peak from diffraction

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

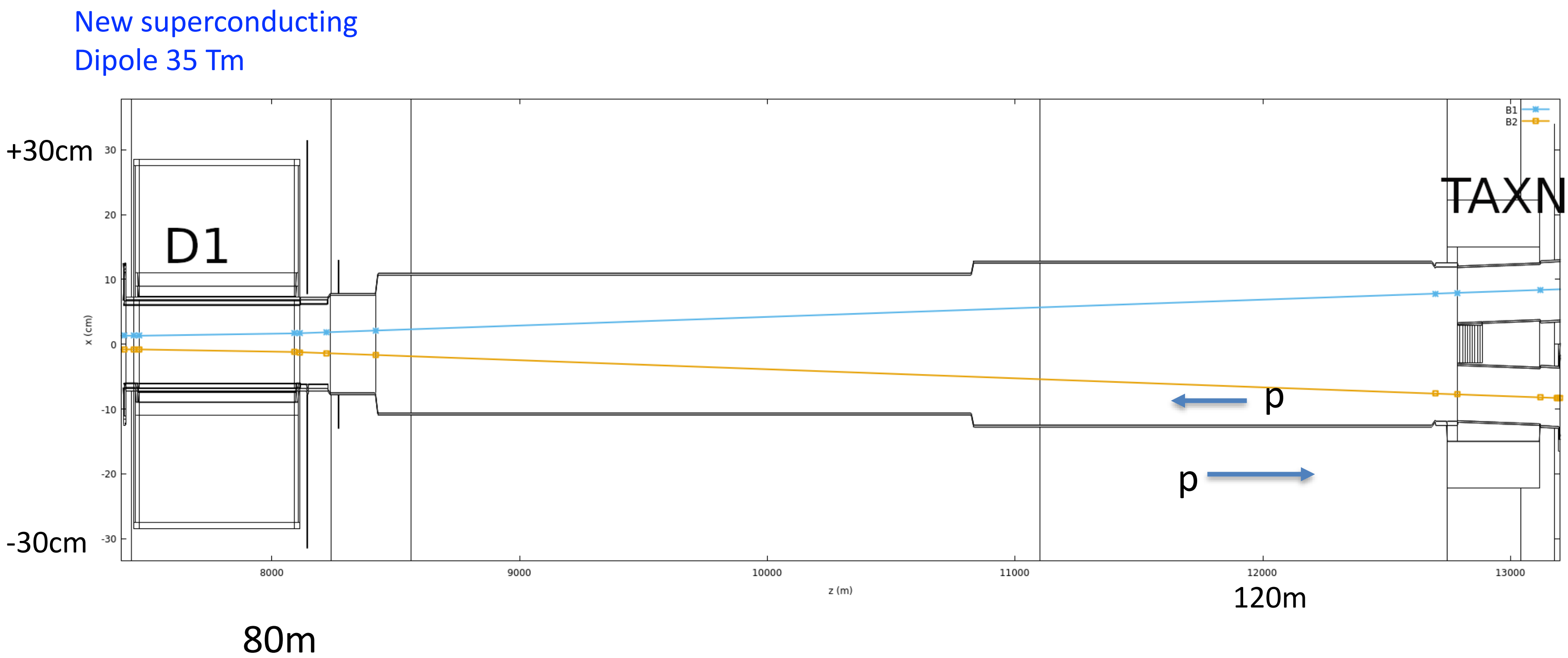


~ 100 x Acc/bin/sec if μ ~ 3



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

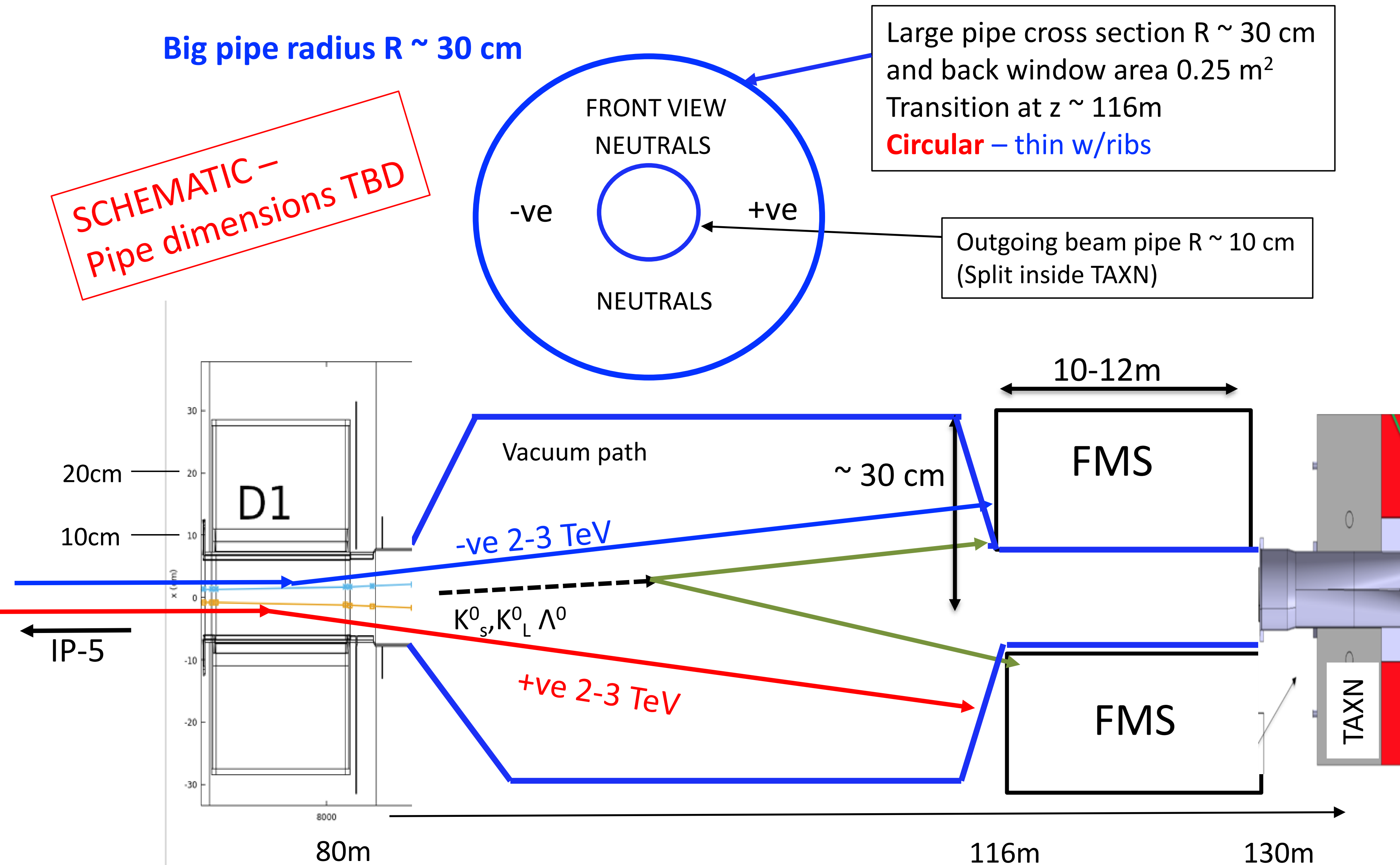
Pipe region as currently planned for Run 4
TOP VIEW



Propose: new pipe with radius ~ 30 cm, length ~ 30 m

Vincent Baglin's talk tomorrow

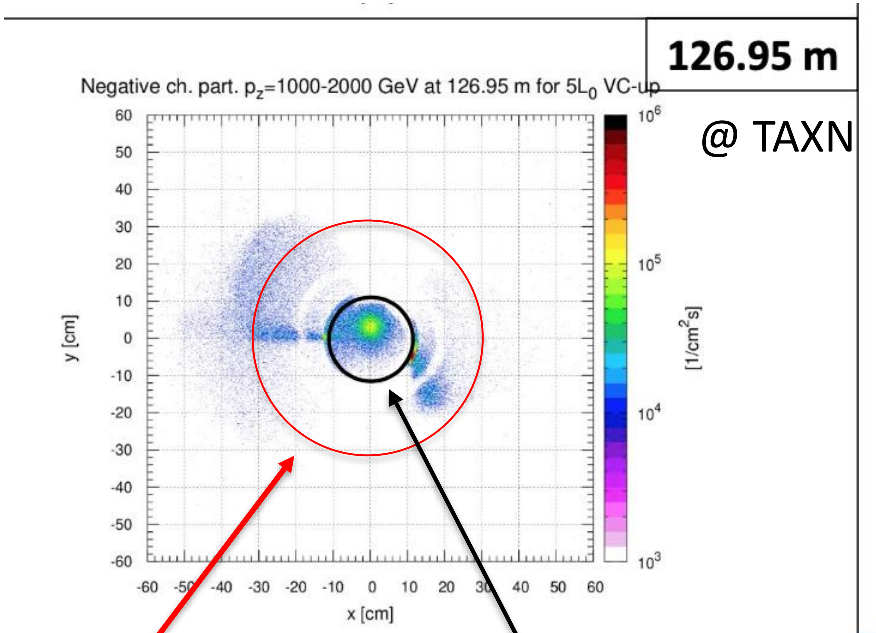
TOP (BENDING) VIEW

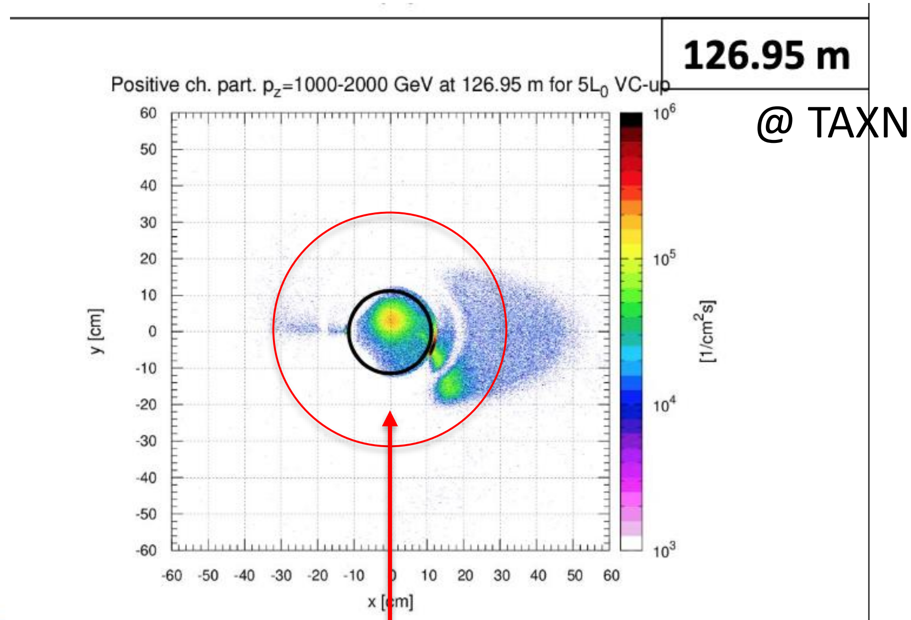


Marta Sabate Gilarte's talk

NEGATIVE particles 1 – 2 TeV
(through D1 aperture)

POSITIVE 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

No primary charged
Particles UP & DOWN

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

Same techniques as CMS-HL-LHC Forward detectors
Only small overall dimensions – 0.25m^2, shapes
Julie Hogan's talk

At back of big pipe, over R ~ 10 cm – 30 cm:
Detectors over 10 – 12 m in front of TAXN at 127 m:
Thin vacuum window (minimise mult.scatt. over most of area)
Precision tracking (pixels and/or strips) over ~ 2 m (θ_x and θ_y to few μrad)
Timing (~ 20 ps) to constrain track pairs (e.g. LGAD)
High granularity **EM calorimeter** (e^+e^- and $\gamma\,\gamma$)
Imaging **hadron calorimeter**: hadron E measurment and muon filter
== Fe toroid magnet full φ
Muon tracking behind calorimeter (e.g. GEMs)
== TAXN behind (shields the back)

Transition Radiation Detectors only needed for Low PU spectra for Mode A (hadrons)
Not really essential (?) for HL LLP search – if assume h = π

At high P-U separate trigger and data stream – no need to combine with central
(Only in low – PU mode SMP-HAD)

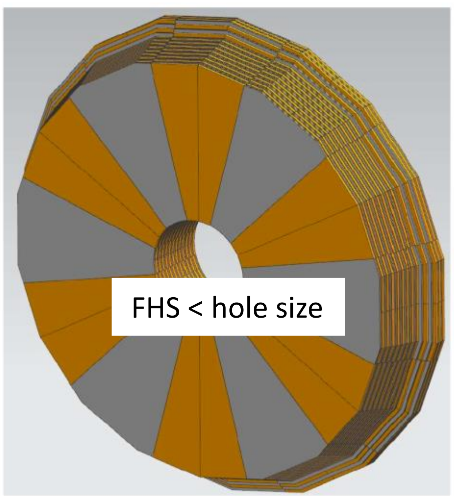
Tracking

Julie Hogan's talk

Precision tracking immediately behind vacuum pipe window – as thin as allowed (ribs)
No field behind D1 so straight tracks.

Hadron identification : π, K, p, d, .. **TRANSITION RADIATION DETECTOR**
- incorporates tracking

Mike Cherry's talk



CALORIMETER (toroid for μ deflection)

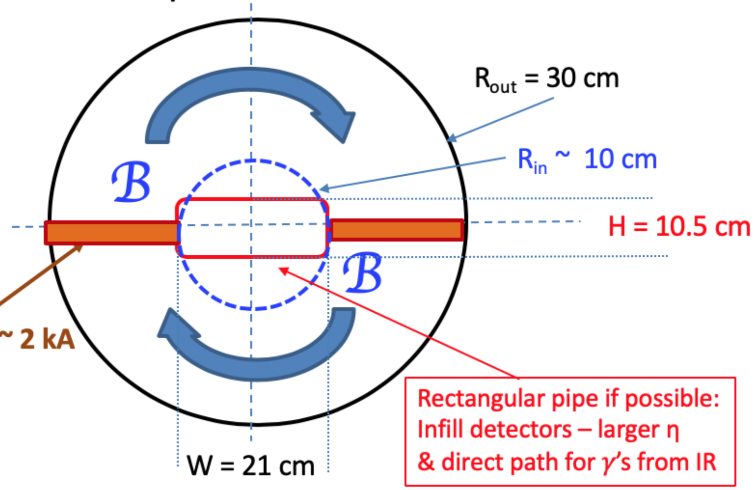
FH. *i*	FMS
Imaging: readout with Si pads/cells ~ 1 cm^2	
R_{inn} ~ 40 cm.	Cf FHS 10 cm
R_{out} ~ 180 cm.	Cf. FHS 30 cm
Angled	Not angled
Area ~ 10 m^2.	Area ~ 0.25 m^2

Julie Hogan's talk

MUON CHAMBERS

TO DO: Layout a detector combination with Run 4 detectors as default and simulate.

Magnetised hadron calorimeter toroid concept – as HGCAL + coil

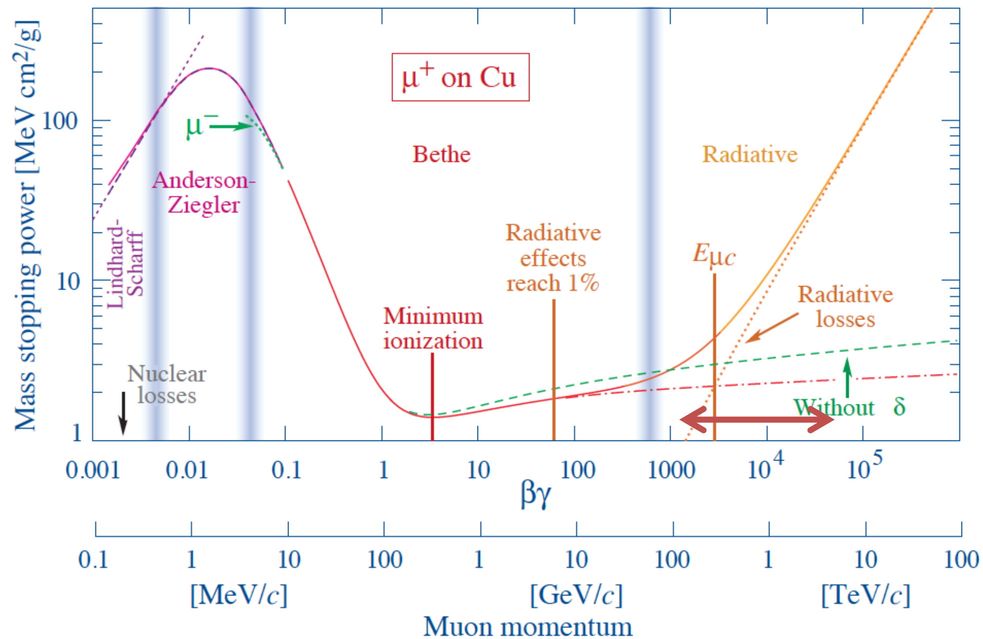


IRON Plate thickness = 12 x 35mm – (12-24) x 68mm
Field in Fe ~ 2T (saturation) at small R
Not uniform – decreases with R

TODO: Calculate bending with multiple scattering vs p(μ) over full range → M(μ+ μ-) resolution

Vladimir Kashikhin's talk yesterday

Total signal of μ-track through Calo



Several possible μ-tracking technologies
0.25 m² x N (~4?) layers
Alexei Safonov : GEMs suitable, and almost "off-the-shelf" now.

Note: shielded by TAXN at back

Forward production of antinuclei : antideuterons, anti-He?

Antideuterons discovered at the CERN PS (1965), seen at AGS, Serphukov, NAL.

Observed at the first pp-collider (ISR) at large angles:
B.Alper et al., Phys.Lett. 46B (1973) p.265 : dbar/π- = $(5 \pm 1)\ 10^{-5}$
and small angles:
M.G.Albrow et al., Nucl.Phys.B 97 (1975) p.189 : dbar/π- = $(7.6 \pm 2.3)\ 10^{-6}$

Those were searches for new charged long-lived particles.

How produced in pp? Coalescence model.
pbar + nbar close in phase space (< p_0 parameter ~ 25 MeV?) stick together.

Renewed interest for **dark matter annihilations in galaxy center**
Need to know Standard Model production. (Cholin's talk at Dublin 2019)

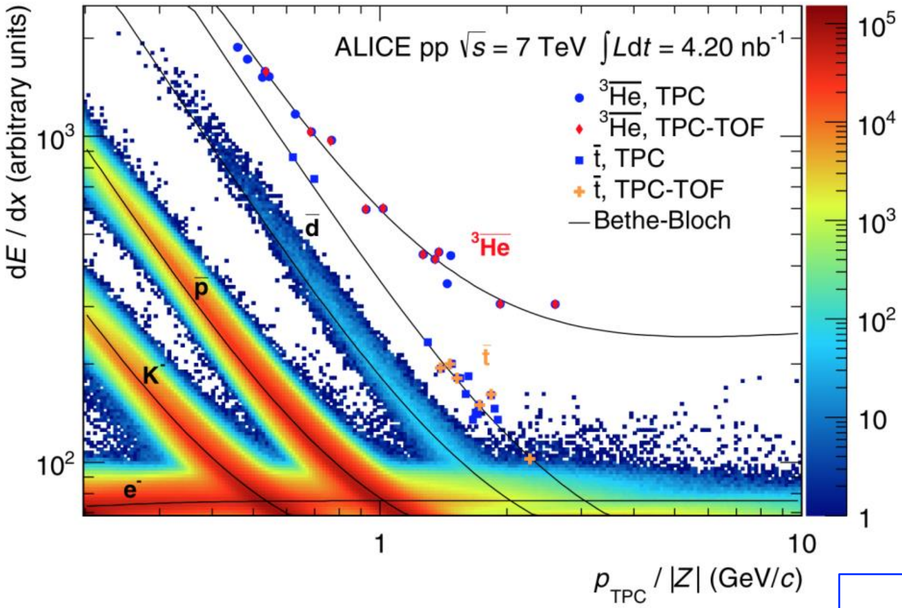
Very clean signature in SAS:
Negative curvature - > p/Q, dE/dx - > |Q|, Calorimeter - > E, TRD - > E/m

Anything novel? E.g. strangelets in heavy ion (pO and OO) fragmentation region?
(Light quasi-stable nuclei with s-quarks replacing d-quarks -unusual Q/M)

ALICE has best LHC data on antinuclei so far: Central region: |y|< 0.5 at $\sqrt{s} = 7$ TeV pp.

PHYSICAL REVIEW C **97**, 024615 (2018)

Production of deuterons, tritons, ^{3}He nuclei, and their antinuclei in *pp* collisions at $\sqrt{s} = 0.9$, 2.76, and 7 TeV



Topical interest, possible signals of dark matter annihilation in galaxy

Physics Reports 618 (2016) 1–37

Contents lists available at ScienceDirect

Physics Reports

ELSEVIER

journal homepage: www.elsevier.com/locate/physrep

Review of the theoretical and experimental status of dark matter identification with cosmic-ray antideuterons

T. Aramaki[a,b], S. Boggs[c], S. Bufalino[d], L. Dal[e], P. von Doetinchem[f,*],

Can probably make a special trigger for « heavier than protons » & get high statistics. ??

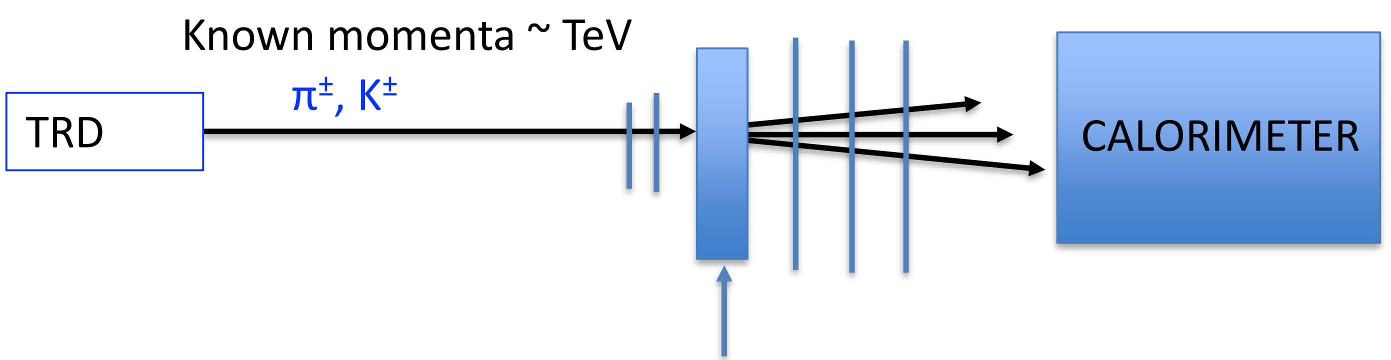
ANOTHER POTENTIAL USE OF FHS:

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

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:



Thin TARGETs

CH_4, C - subtract

Very simple addition:

σ_{inel}, N_{ch}, σ_{el},

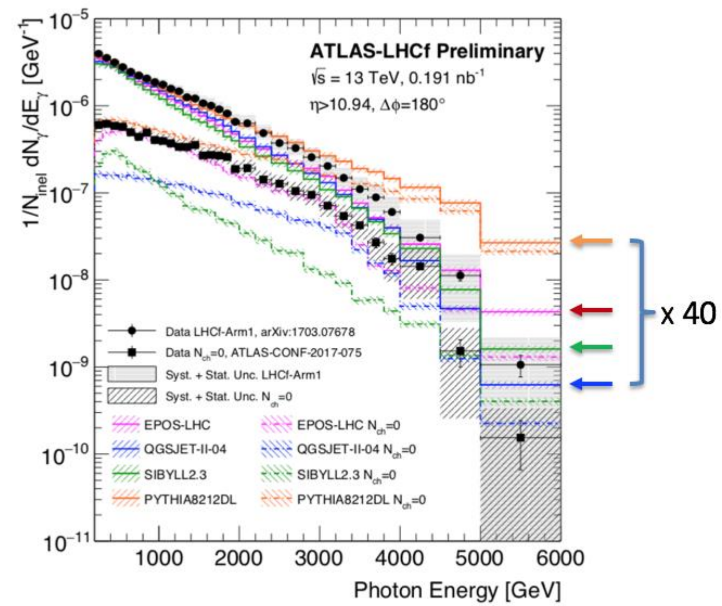
Implications for the FCC = Future CERN Colliders
100 TeV pp and heavy ion colliders FCC

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!



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 being calculated by Marta for some channels …
Details will need to be calculated for real design of system – and backgrounds

Potentially:

J/ψ, $\psi(2S) \rightarrow \mu+\mu-$, $\chi_c \rightarrow J/\psi + \gamma$, 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

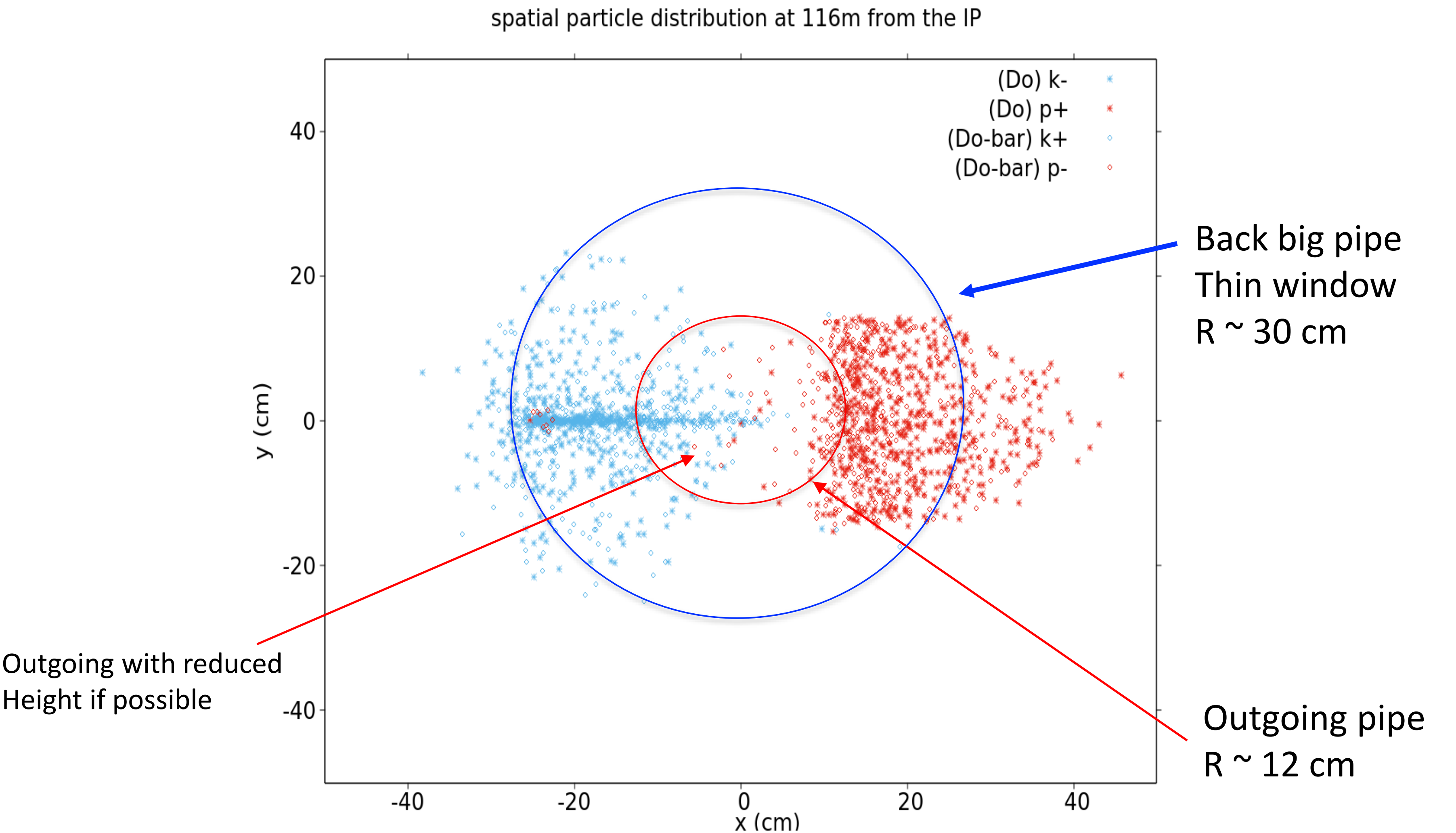
Muons from π, K decay will be known, and their decay lengths are very long!

$\gamma c\tau$ (π) = 139 km at 2.5 TeV !
$\gamma c\tau$ (K+) = 18.5 km at 2.5 TeV !
$\gamma c\tau$ (D^0) = 16.5 cm at 2.5 TeV !

But abundant and - > forward HE μ-neutrinos! (FASERν)

Marta Sabate Gilarte's talk

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



V.Tikhomirov, A.Mufazalova. D0 reconstruction. TRD workshop, 15-16.04.2020

Preliminary study

Some acceptance for $D^0 \rightarrow K\,\pi$ but it is very challenging:

Acceptance small – OK if very well known – signal could be much bigger (Brodsky)

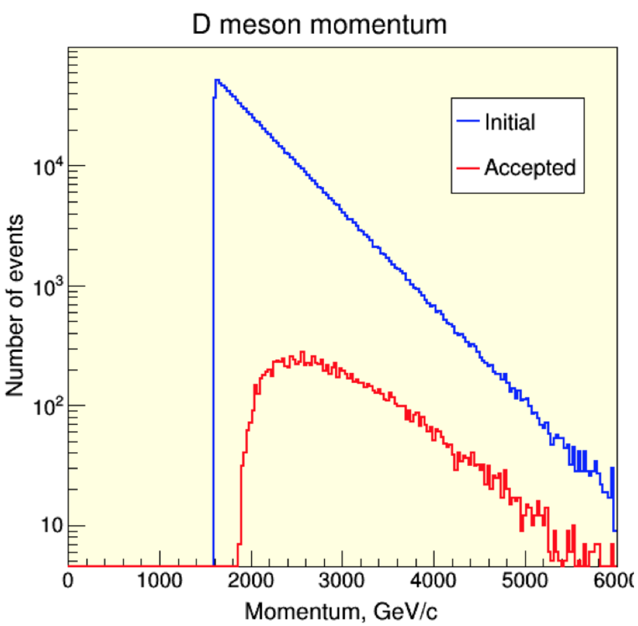
p >> π+ >> K+ so mis-identification critical … TRD challenge

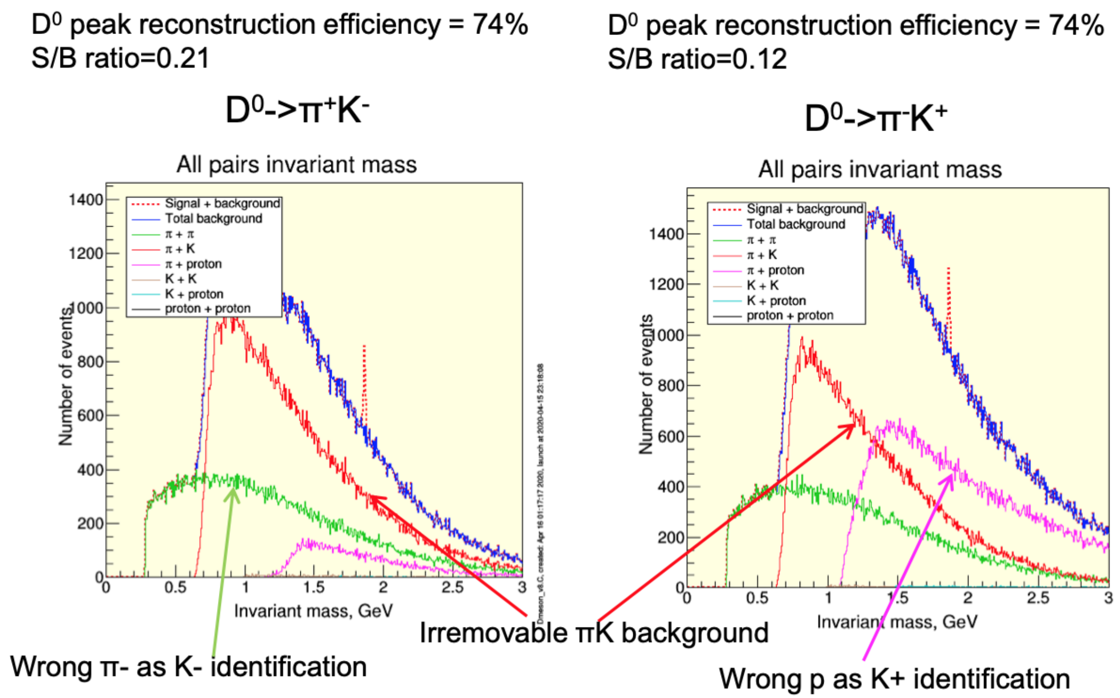
Mike Cherry's talk

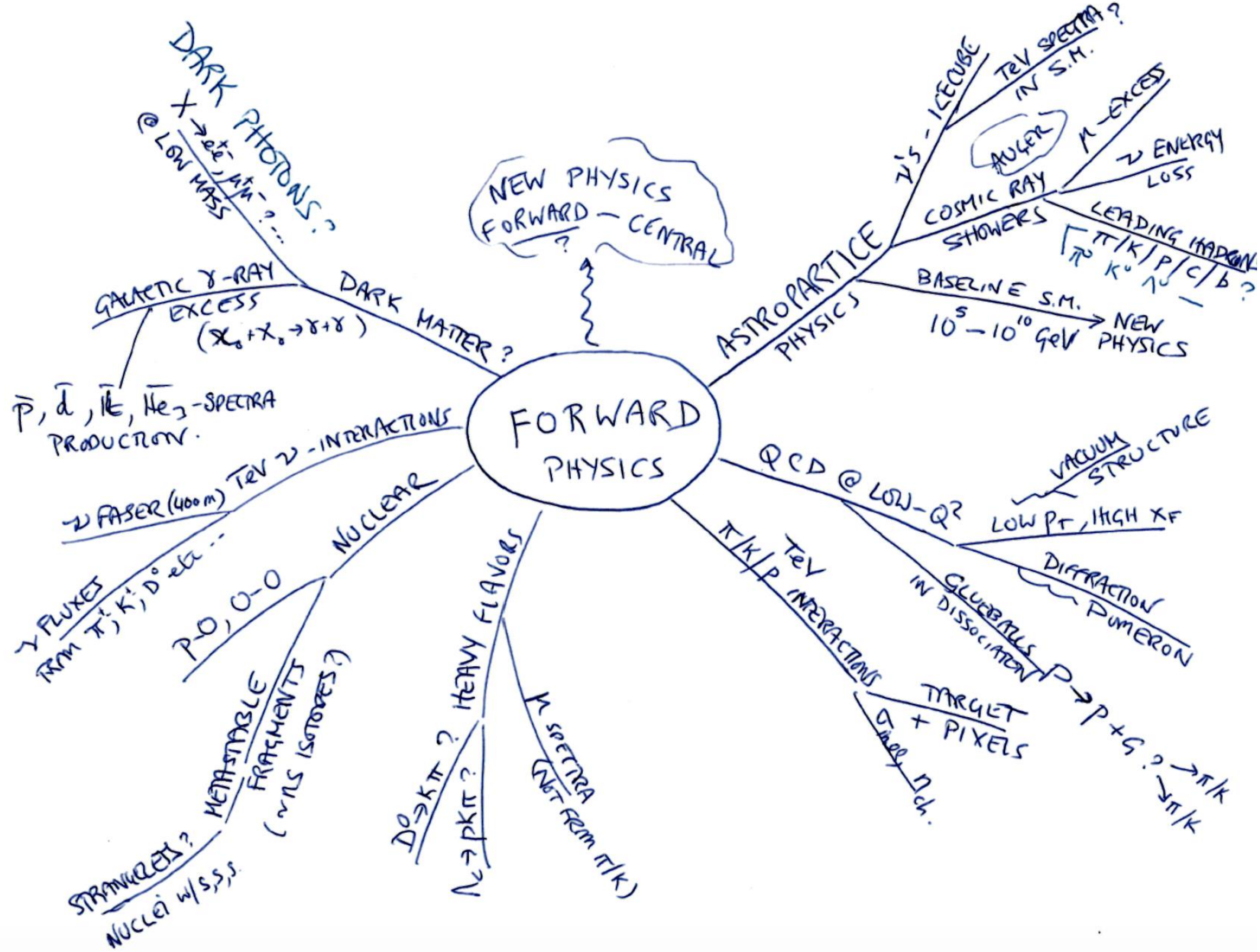
Even with perfect identification, irremovable K π continuum is large.

Unlike central production, do not see decay vertex and $\gamma c\tau\ (D^0)$ = 16.5 cm at 2.5 TeV !

… which smears mass resolution from ~ 6 MeV to ~ 16 MeV






FORWARD PHYSICS
NEW PHYSICS FORWARD — CENTRAL ?
DARK PHOTONS ?
@ LOW MASS
DARK MATTER ?
GALACTIC γ-RAY EXCESS
P̄, d̄, H̄e, H̄e₃ -SPECTRA PRODUCTION.
TeV ν -INTERACTIONS
ν FASER (400 m)
ν FLUXES FROM π±, K±, D° etc ..
NUCLEAR
P-O, O-O
METASTABLE FRAGMENTS (w/ ISOTOPES?)
STRANGELETS ? NUCLEI w/ s,s,s
HEAVY FLAVORS
μ SPECTRA (NOT FROM π/K)
ASTROPARTICLE PHYSICS
ν's - ICECUBE
TeV SPECTRA ? IN S.M.
AUGER
COSMIC RAY SHOWERS
μ -EXCESS
ν ENERGY LOSS
LEADING HADRONS
π/K/P/C/b ?
BASELINE S.M. 10⁵ - 10¹⁰ GeV
NEW PHYSICS
QCD @ LOW-Q²
VACUUM STRUCTURE
LOW pT, HIGH xF
DIFFRACTION
POMERON
GLUEBALLS IN DISSOCIATION
P → P + G ? → π/K → π/K
TeV π/K/P INTERACTIONS
TARGET + PIXELS
nch.

SUMMARY: Propose Forward Multiparticle Spectrometer for CMS Run 4

Low PU charged mode : many valuable measurements in unexplored region
[High Lumi neutral mode: important discovery potential]

Many opportunities to participate towards a CMS Note or other documents

Integrate with HL-LLP mode

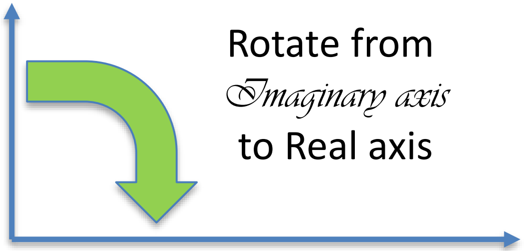
Assemble a possible configuration of Run 4 detectors as spectrometer elements, and possible TRD detectors.

Integrate with full simulation of particles (as started by Marta & Francesco)

Calculate hadron (including c) production spectra in this region with PYTHIA et al. –other MCs

Trigger and correlations with central detector (low PU)

Infrastructure and engineering, etc.



Opportunity for participation and also leadership!

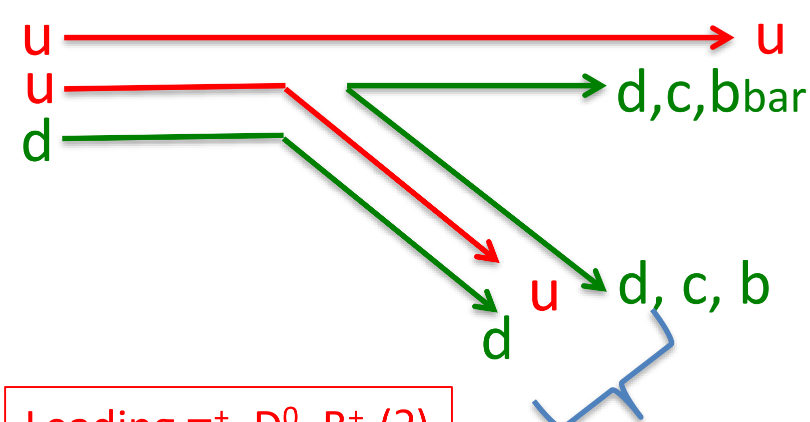
Thank you

Back-ups →

$x_{Feynman} = x_F$ = p(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

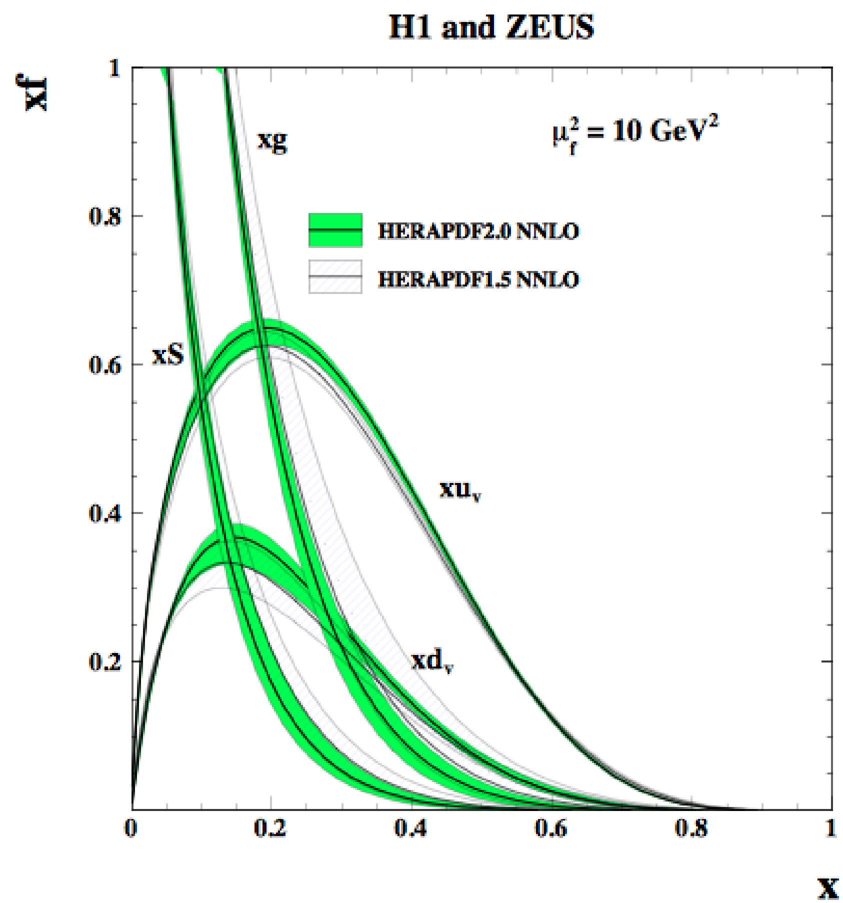


t-channel baryon exchange

Leading π^+, D^0, B^+ (?)

Diffraction dissociation

$x_{Bjorken} = x_{Bj}$ = p(parton)/p(proton)
Major industry at HERA, and these PDFs needed for hard (partonic) interactions at LHC



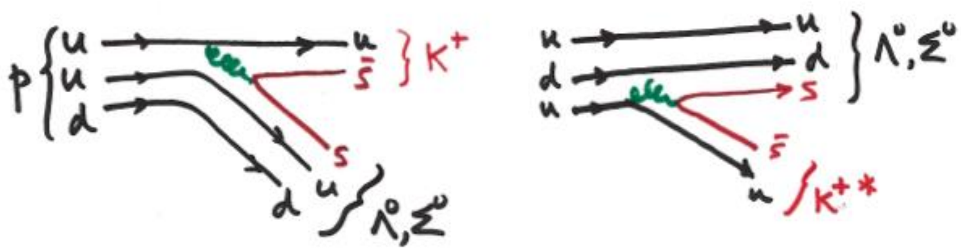
Brodsky: Intrinsic charm – p has {uud$c\bar{c}$} component (1-2%?) → high x_F Λ_c and D^0

Challenge to theorists

Strong Interactions at low-Q^2

Hadron level ~ Regge theory ⟷ Parton level ~ QCD (non-perturbative)

Leading (high x_{Bj}) u-quark or [ud] di-quark picks up an sbar or s in "string-breaking" or from s-sbar sea, to make a leading K^+ or Λ^0, Σ^0
$\gamma c\tau(\Lambda)$ at 4.4 TeV is 316 m, → $p\pi^-$ (acceptance?). $\Sigma^0 \to \Lambda^0 + \gamma$ (100%, prompt)



Dissociation products sharing beam momentum (p opposite?)

Quark line description of leading K^+ or Λ^0, Σ^0

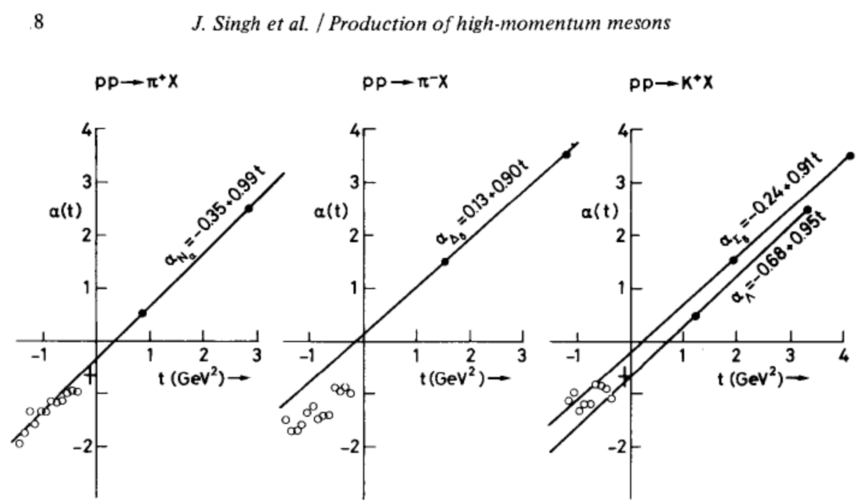


Fig. 9. Effective trajectories $\alpha(t)$ obtained from a one-term triple-Regge fit, see text.

Virtual (negative mass², t-channel) exchanged baryon or meson described in Regge phenomenology :
Analyticity, unitarity and crossing symmetry + continuous complex angular momentum.

Derive it from QCD !! ?

Low PU charged mode : many valuable measurements in unexplored region
High Lumi neutral mode: important discovery potential

Some opportunities to participate:

Simulate beam line, magnets as absorbers etc.

Marta Sabine Gilate's talk +

Assemble a possible configuration of Run 4 detectors as spectrometer elements

Calculate hadron production spectra in this region with PYTHIA et al. –other MCs

Acceptances also for hadron pairs e.g.

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.

Simulate sensitivity to LLIs as fn (M, τ, σ)

Opportunity for participation and leadership

Some next steps (a plan)

NEED CALCULATIONS!

LS 3 planning for Run 4 2027+ is now firming up
Need to get officially included this year or it may be too late!
LHC will start studies only when CMS officially asks

March 20th (Friday) present the Low-lumi hadron spectroscopy to **SMP-HAD** subgroup
Intro (MGA) - Cosmic Ray MC's (Tanguy Pierog, KIT) – TRD status (Mike Cherry, LSU)
March 27th (Friday) present the HL LLI search to **EXO-LLI** subgroup.
(? Matt Low, Christina Yang Gao anything yet?)
April 16+17 LHC Forward Physics open meeting (not restricted to CMS)
Thursday 16th: Progress in Transition Radiation Detector development for TeV hadron ID
Friday 17th: FMS issues:
Machine configuration, beam pipe
Anticipated spectra through D1 – single hadrons, charm D0, antinuclei …
Cosmic ray shower simulation programs
Detector configuration possibilities
Sensitivity to LLI's (M, couplings, lifetimes etc.) cf FASER etc.
Etc.

WRITE DOCUMENT!

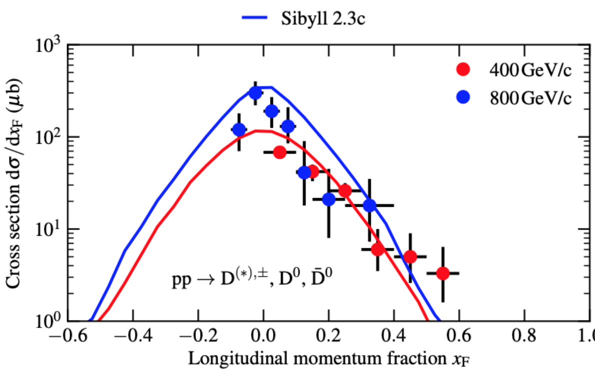
Grow team of interested contributors. TRD group inside CMS (?) or outside to join.
April/May : request presentation to CMS weekly

The hadronic interaction model SIBYLL 2.3C and inclusive lepton fluxes

A. Fedynitch, F. Riehn, R. Engel, T.K.Gaisser and T. Stanev, arXiv:1806.04140

TABLE II. Experiments that collected data on charm production including the corresponding projectile-target configuration and the accessible longitudinal phase space. These data have been used for model development and parameter estimation.

Name	P_{Lab} (GeV)	$\sqrt{s}$ (GeV)	x_F spectrum	x_F coverage	Beam config.	Ref.
E-769	250	22	yes	$-0.1 < x_F < 0.8$	p-Nuc	[26, 27]
EHS	400	27.4	yes	$0 < x_F < 0.6$	p-p	[19, 20]
MPS	800	39	yes	$-0.1 < x_F < 0.4$	p-p	[28]
HERA-B	920	42	no	$-0.1 < x_F < 0.05$	p-Nuc	[93]
STAR	21 TeV	200	no	$-0.03 < x_F < 0.03$	p-p	[13]
PHENIX	21 TeV	200	no	$-0.003 < x_F < 0.003$	p-p	[15]
ALICE	4 PeV	2.76 TeV	no	$-0.005 < x_F < 0.005$	p-p	[12]
	26 PeV	7 TeV	no	$-0.004 < x_F < 0.004$	p-p	[11]
LHCb	26 PeV	7 TeV	no	$0.002 < x_F < 0.1$	p-p	[2]
	90 PeV	13 TeV	no	$0.002 < x_F < 0.1$	p-p	[3]



All central region

Maximum $x_F = 0.1$ by LHCb, only at high p_T because $2.0 < y < 4.5$ (central)

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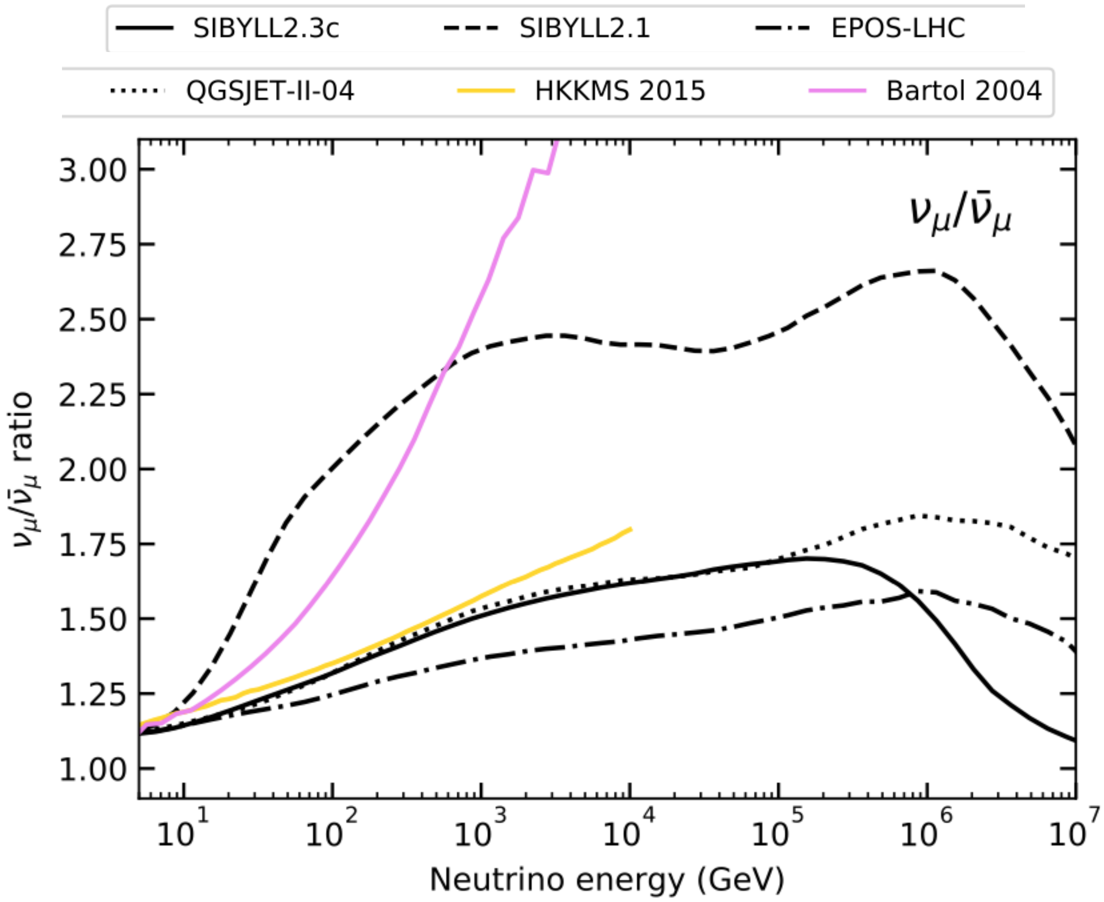

To illustrate the uncertainties in expected ν fluxes from cosmic ray showers

Refining and tuning the models will impact UHE CR and ν physics

From IR5 to first quadrupole Q1

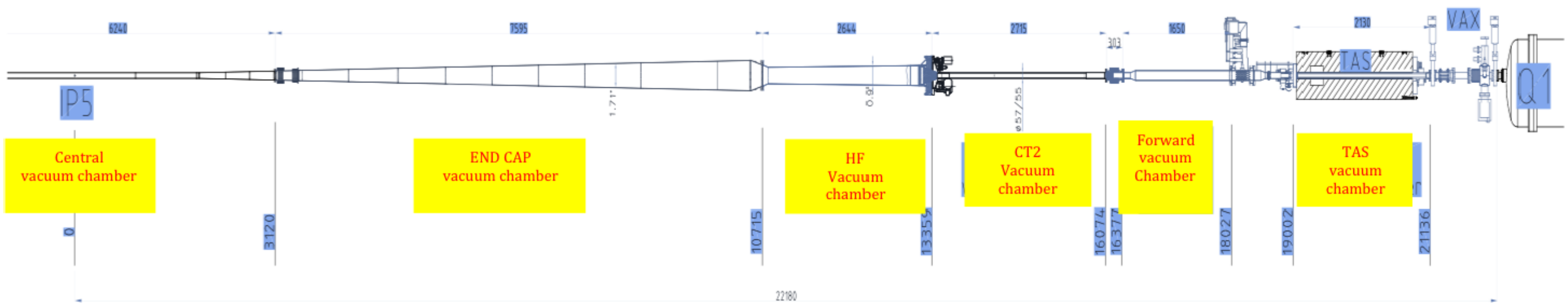

Figure 11.9: Layout of CMS beam-pipe from interaction point to first quadrupole. All dimensions are in millimeters.

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

arXiv:1811.02047v1

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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

Short write-up
But then location uncertain
Only L&R considered
U&D is later addition

Presentations at Forward and Diffractive Workshops in 2019:
Dublin, Forward LHC Physics, June 2019
Nicosia, Cyorus Low-x, August 2019
Guanajuato, Mexico November 2019: Forward LHC & Cosmic Rays etc,