Spectrometers for Multi-TeV Forward Particles at the LHC

Michael Albrow, Fermilab

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

Some physics topics: single- and two- particle inclusive and full event structures

TeV particles through 30 Tm spectrometer magnets, special vacuum chamber

Tracking, Calorimetry and Muons

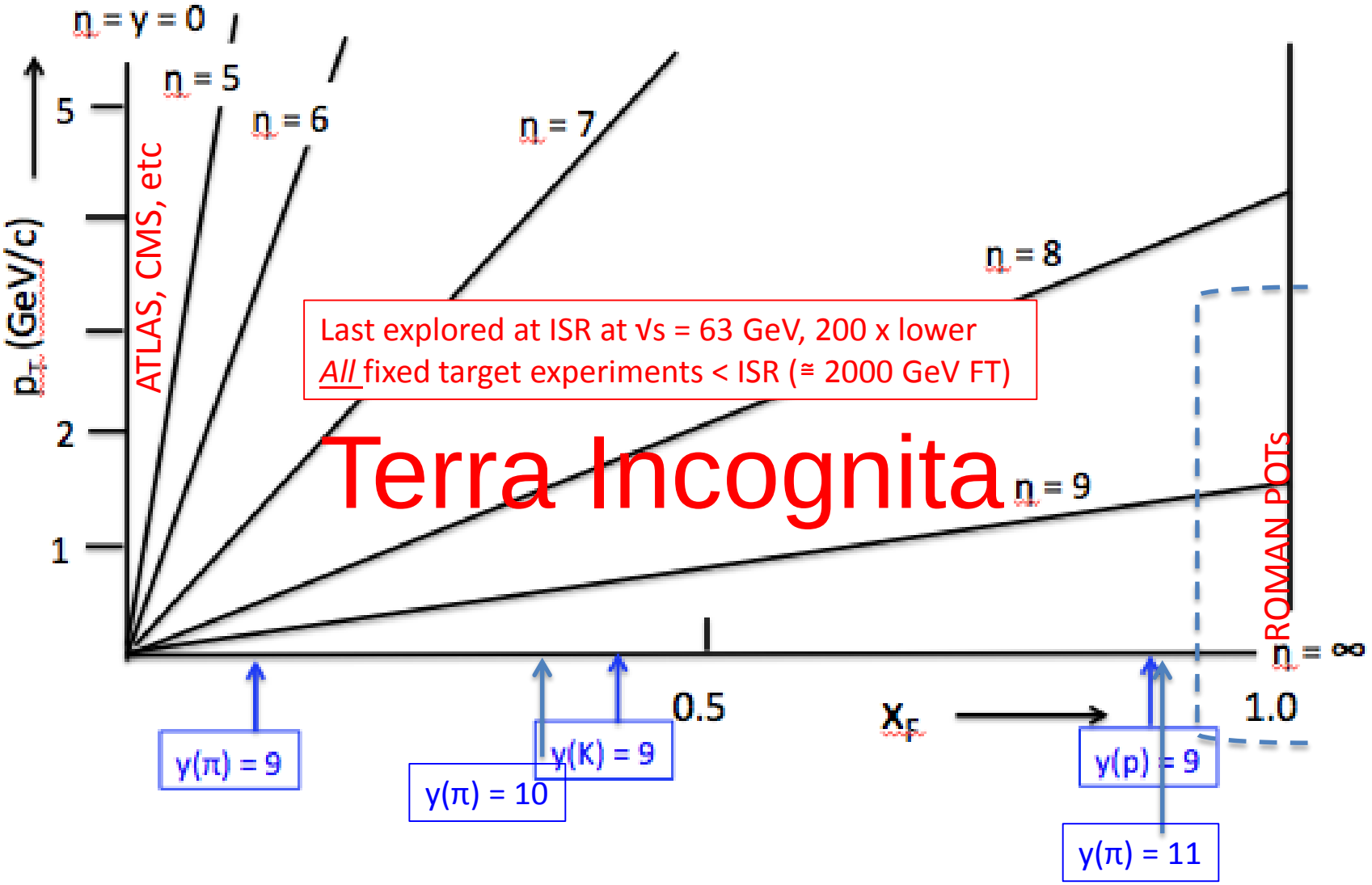
Hadron identification : π, K, p with transition radiation detectors

Extending x_F coverage with bent crystal channeling

What's next? A new collaboration or extensions of ALICE and LHCb?

→ Had a 2-day meeting at CERN Oct 1st & 2nd to discuss this (~ 30 participants)

Thanks to participants and their slides



ZDC, LHCf measure neutrals (n, $\pi^0 \rightarrow \gamma\gamma$) at very small angles.

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).

Special vacuum chamber design for particles to emerge through minimal material

Precision tracking (silicon strips or pixels) over about 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

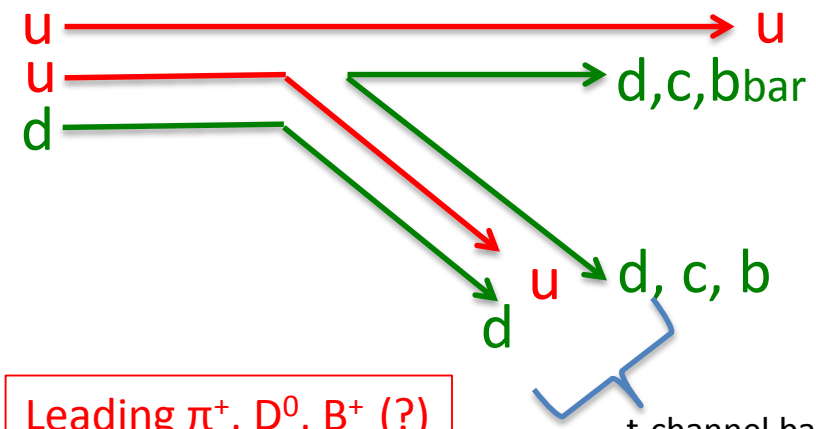
Muon tracking behind calorimeter

Bent crystal to channel and so accept highest momenta (>~ 4.5 TeV, ~4 mrad bend)

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

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

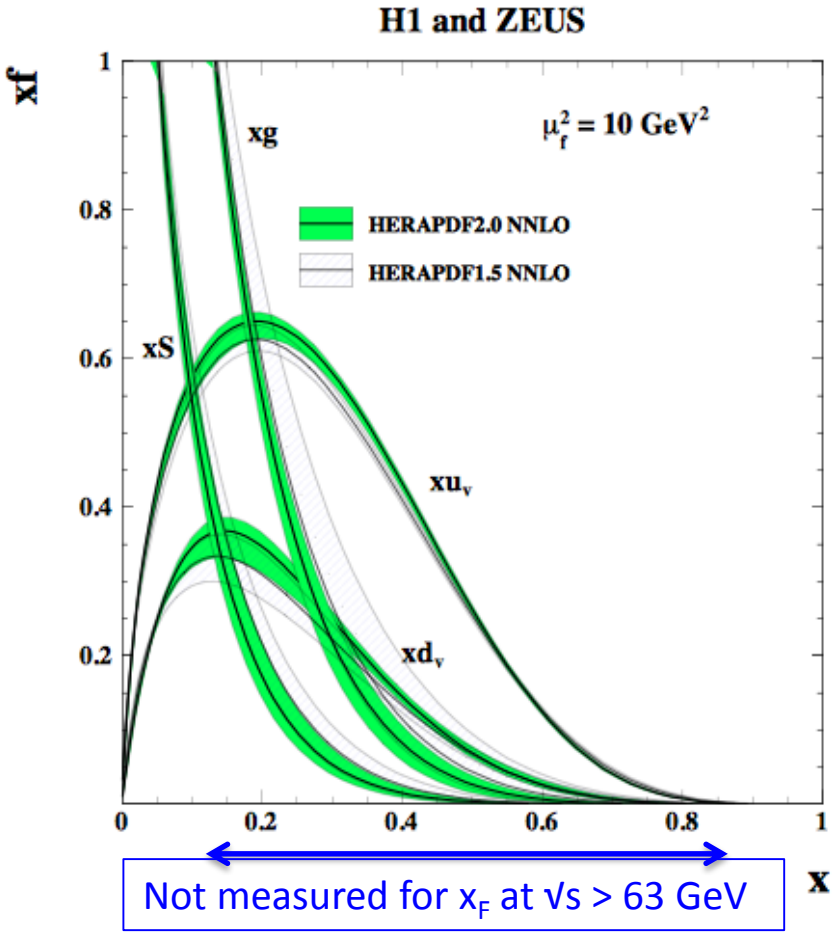
E.g. p → π^+ is from leading u adding a dbar
p → π^- is from leading d adding a ubar
Ratio at high x reflects u:d in p



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



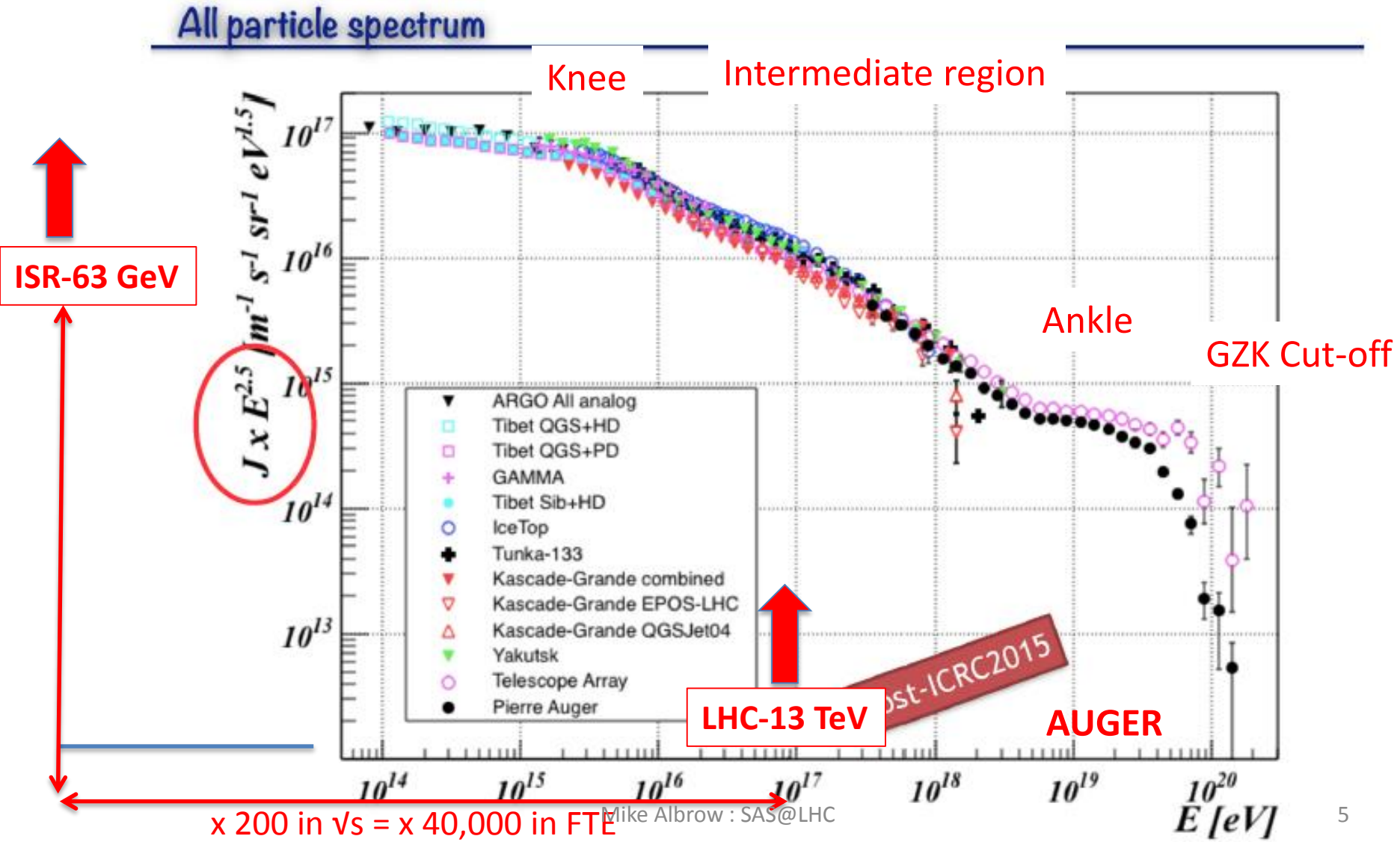
Not measured for x_F at √s > 63 GeV

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.

COSMIC RAY SHOWERS: ASTROPHYSICS CONNECTION

Lipari, SAS@LHC

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



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

37 years ago !

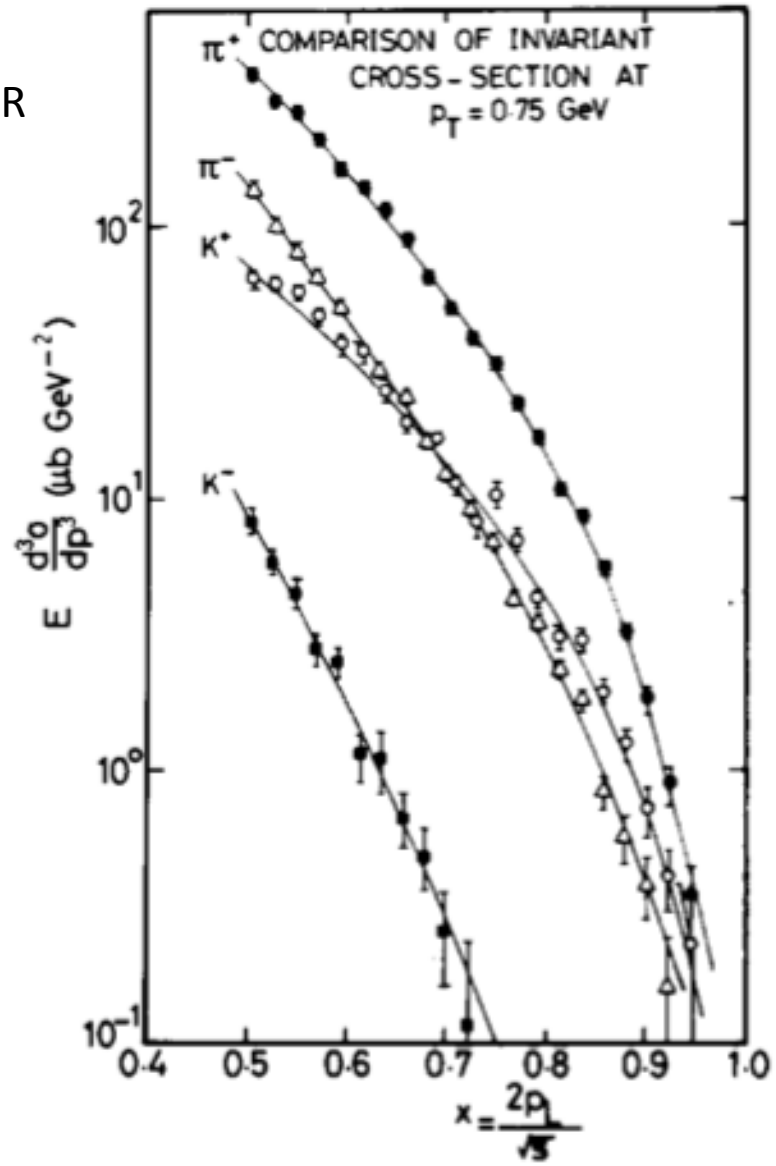


Fig. 2. Invariant cross sections for p + p → meson + X, for p_T = 0.75 GeV, a function of $x = 2p_L/\sqrt{s}$. The curves are empirical fits of the form $A \exp\{K(1-x)^C\}$ for $\pi^{\pm}$, K^+ described in the text. The curve for K^- is hand-drawn. The behaviour at other p_T values is similar.

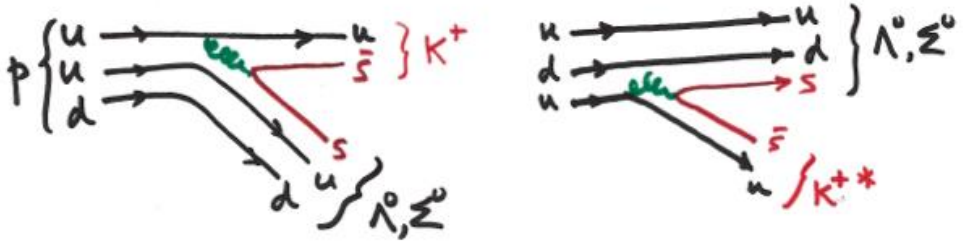
Challenge to theorists

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?). $\Sigma^0 \rightarrow \Lambda^0 + \gamma$ (100%, prompt)



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

Virtual (negative mass^2, t-channel) exchanged baryon or meson described in Regge phenomenology :
Analyticity, unitarity and crossing symmetry + continuous complex angular momentum.

Derive it from QCD !! ?

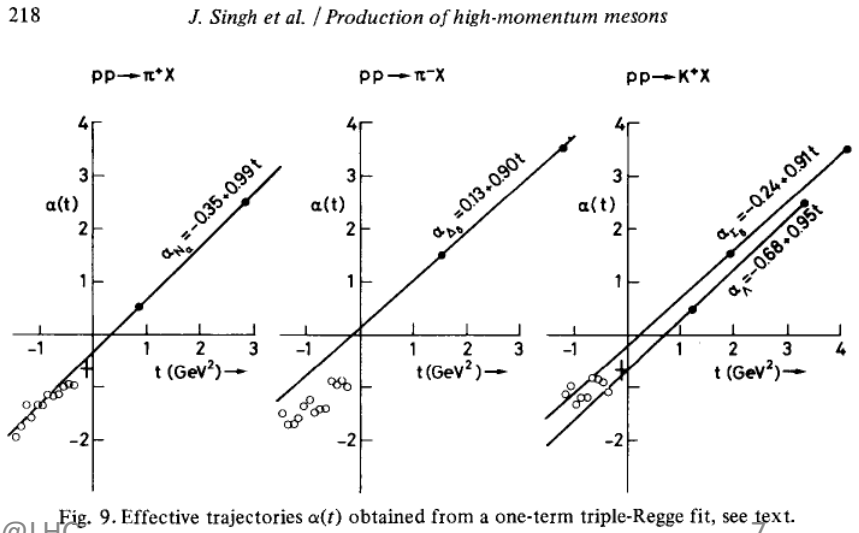
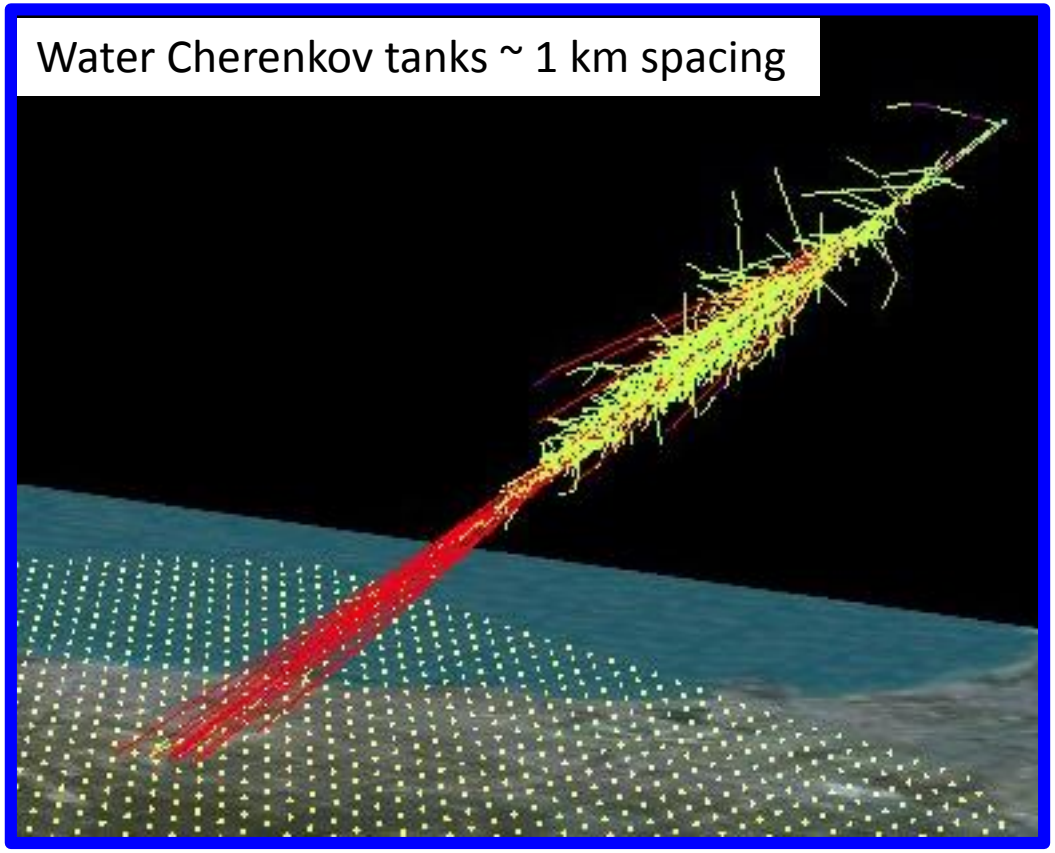


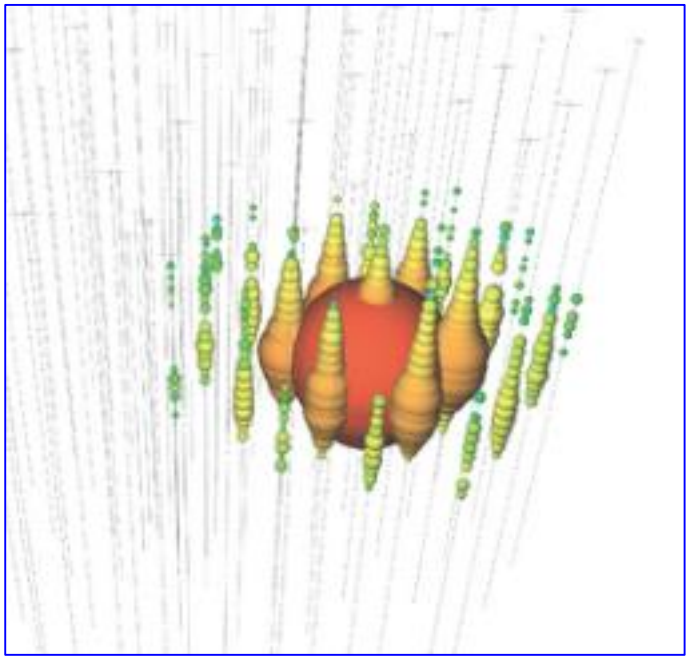
Fig. 9. Effective trajectories $\alpha(t)$ obtained from a one-term triple-Regge fit, see text.

COSMIC RAY SHOWERs

Simulated UHE Cosmic ray shower over Auger observatory in Argentina



ICECUBE Event 20 : 1140 TeV ν



PMTs in Antarctic ice, 1 km^3

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

MUONS! Neutrinos!

Forward charm can be measured in SAS@LHC
J/ψ, Kπ, e, μ, … ?

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

DPMJET predictions
Could be quite different!

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

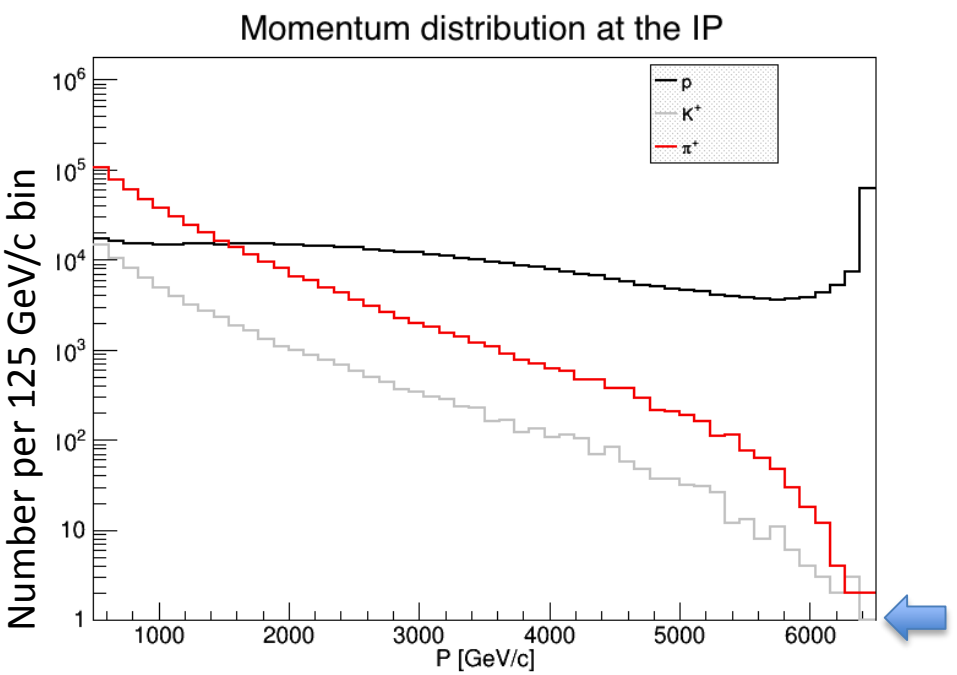
In 1 second, with 2808 bunches,
Have 30 x 10^6 bunch crossings and
30 x 10^6 x μ(= interactions/X) events.

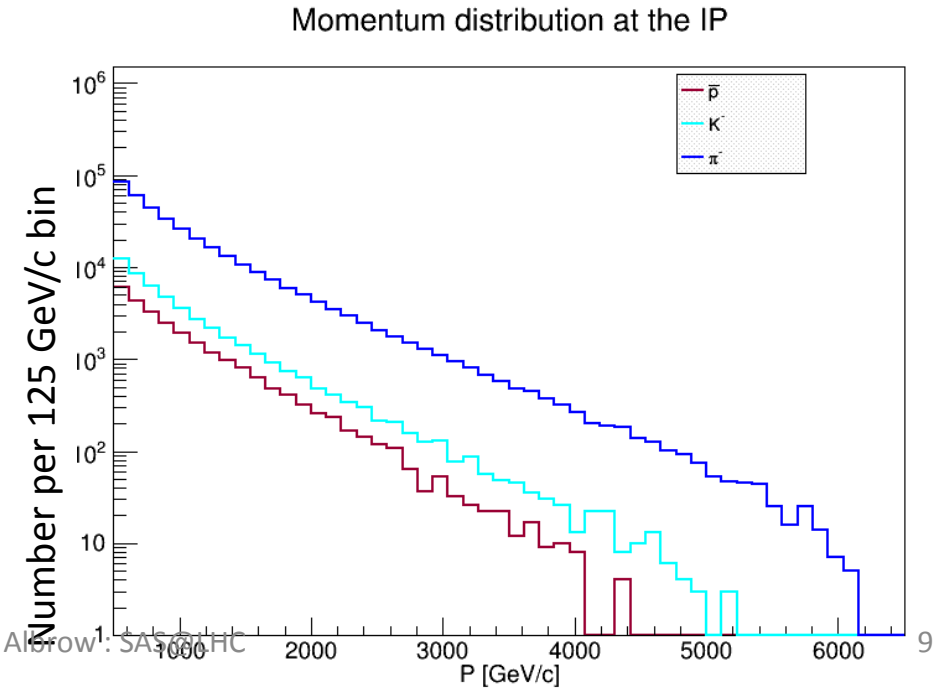
Notes:
At 0.5 TeV (~ central)
$\pi^+ = \pi^-$ & $K^+ \cong K^-$ & K/π ~ 10%

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

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

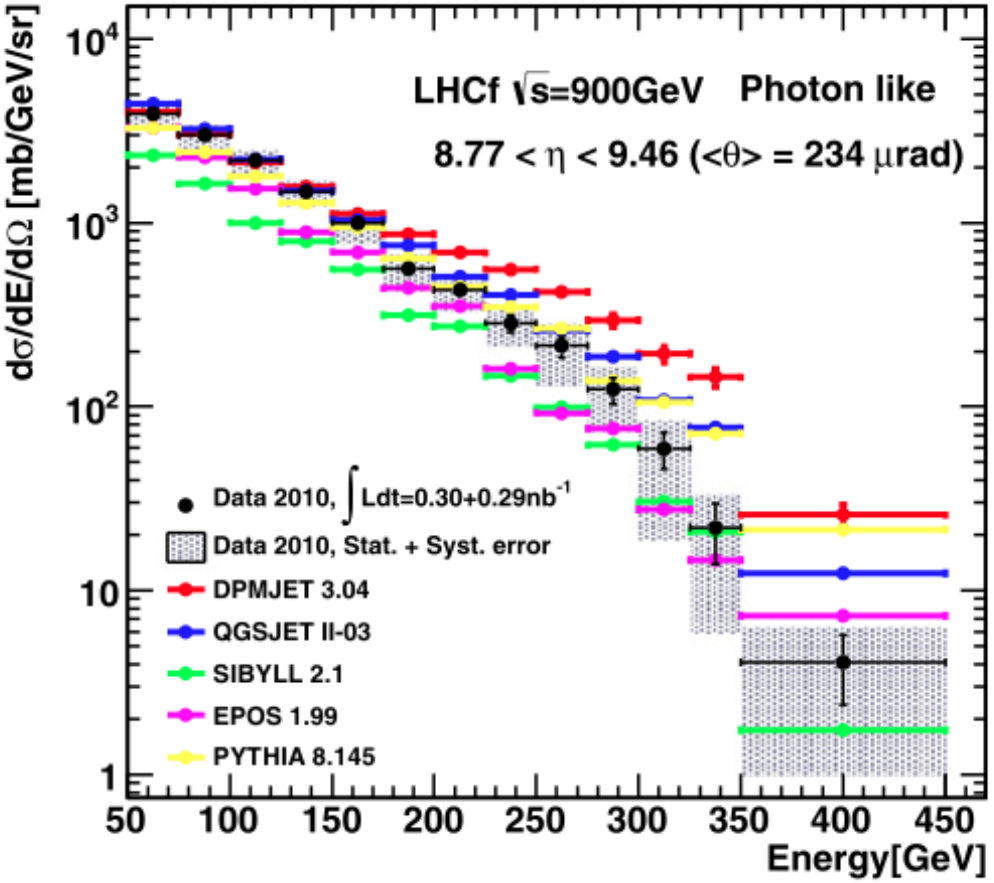
Antiprotons < K^- but only by a factor ~ 0.5





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

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

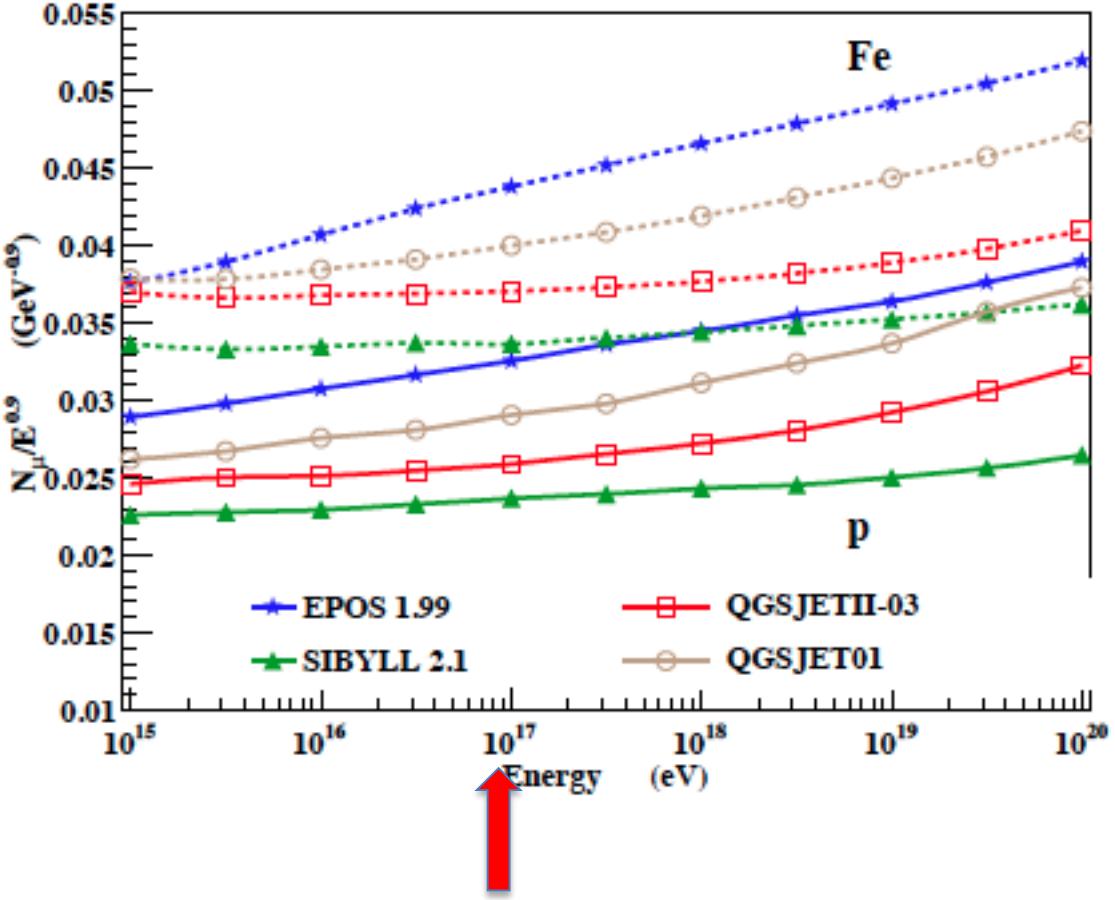


ZDC in CMS
7 λ_I and 8cm x 10 cm
Expect $\sigma(E)/E \sim 15\%$ at 3 TeV

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

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)

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) become more acceptable in future.

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

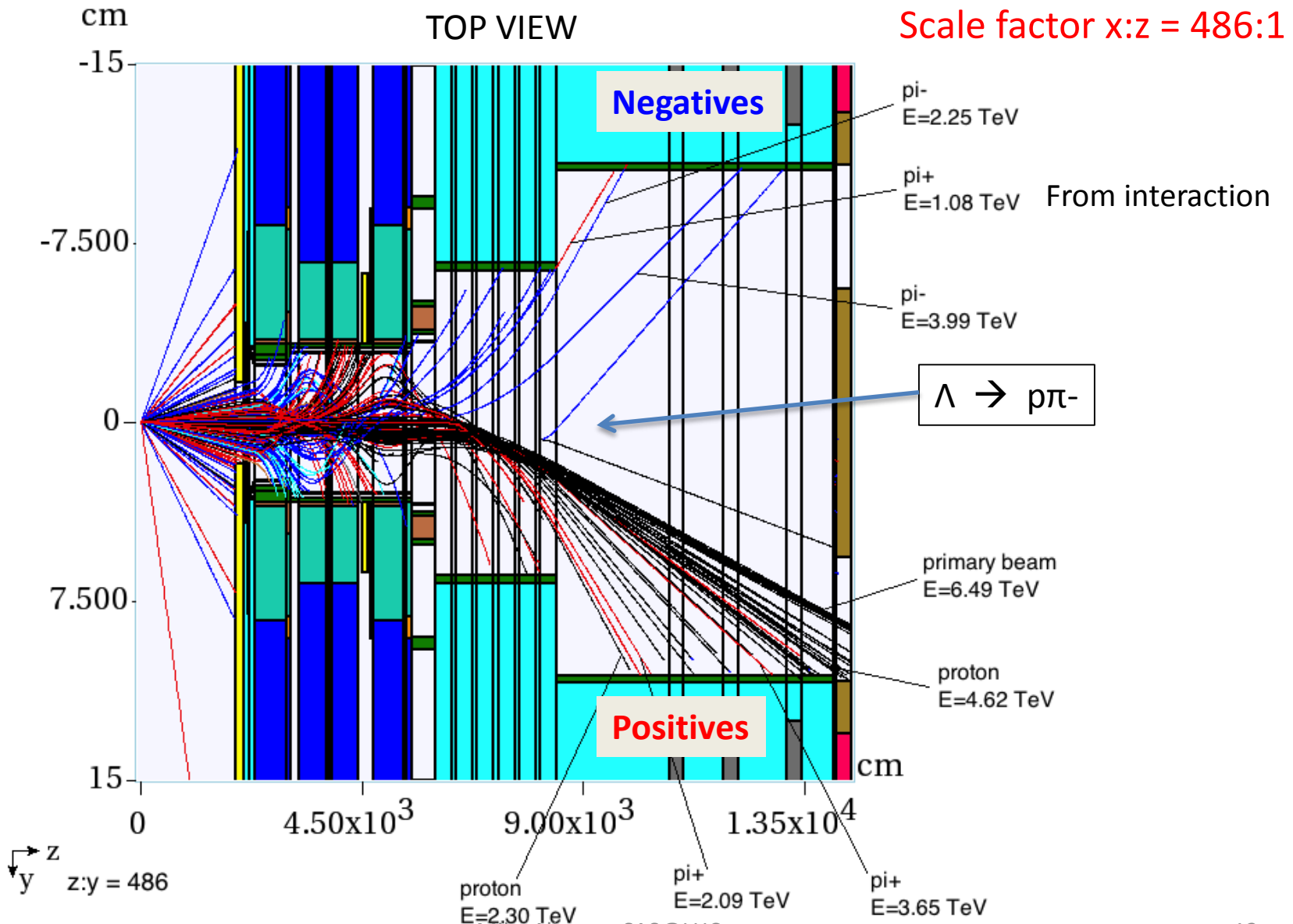
Equivalent FT energy of √s = 13 TeV
$E_{\cong} = s/2m_p$

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

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



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

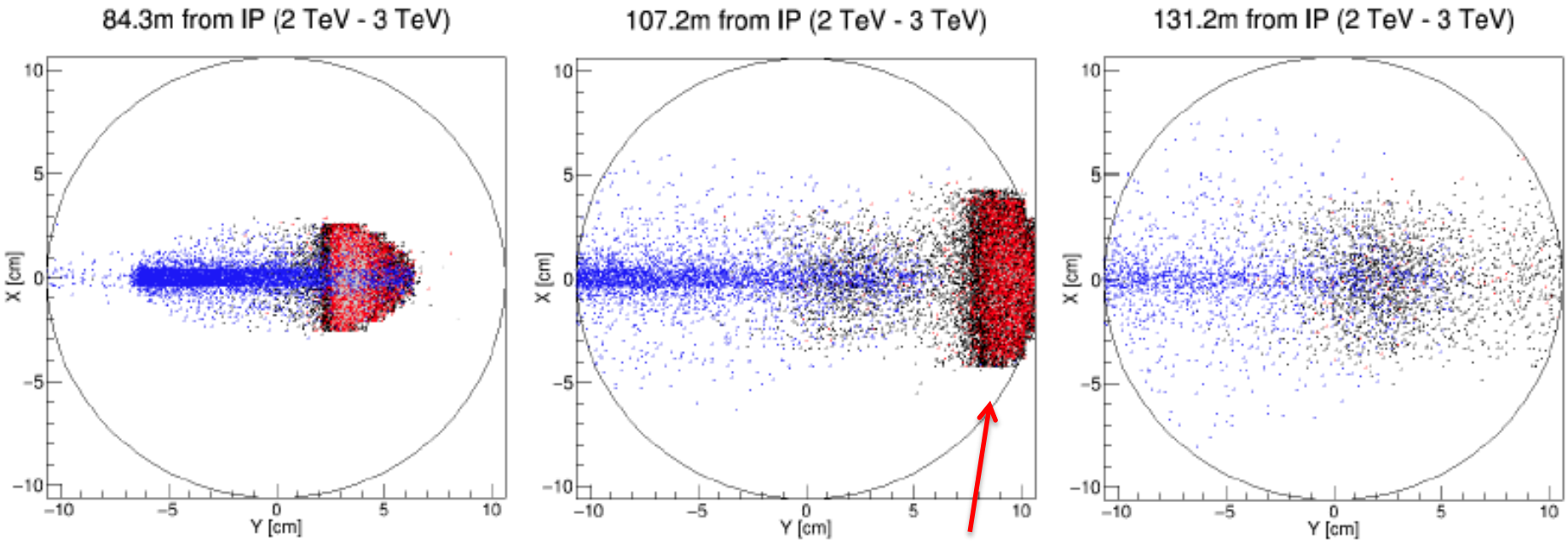
MARS simulation (Nikolai Mokhov and Ottavio Fornieri (summer intern))

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

- ves

+ ves

2 TeV – 3 TeV particles



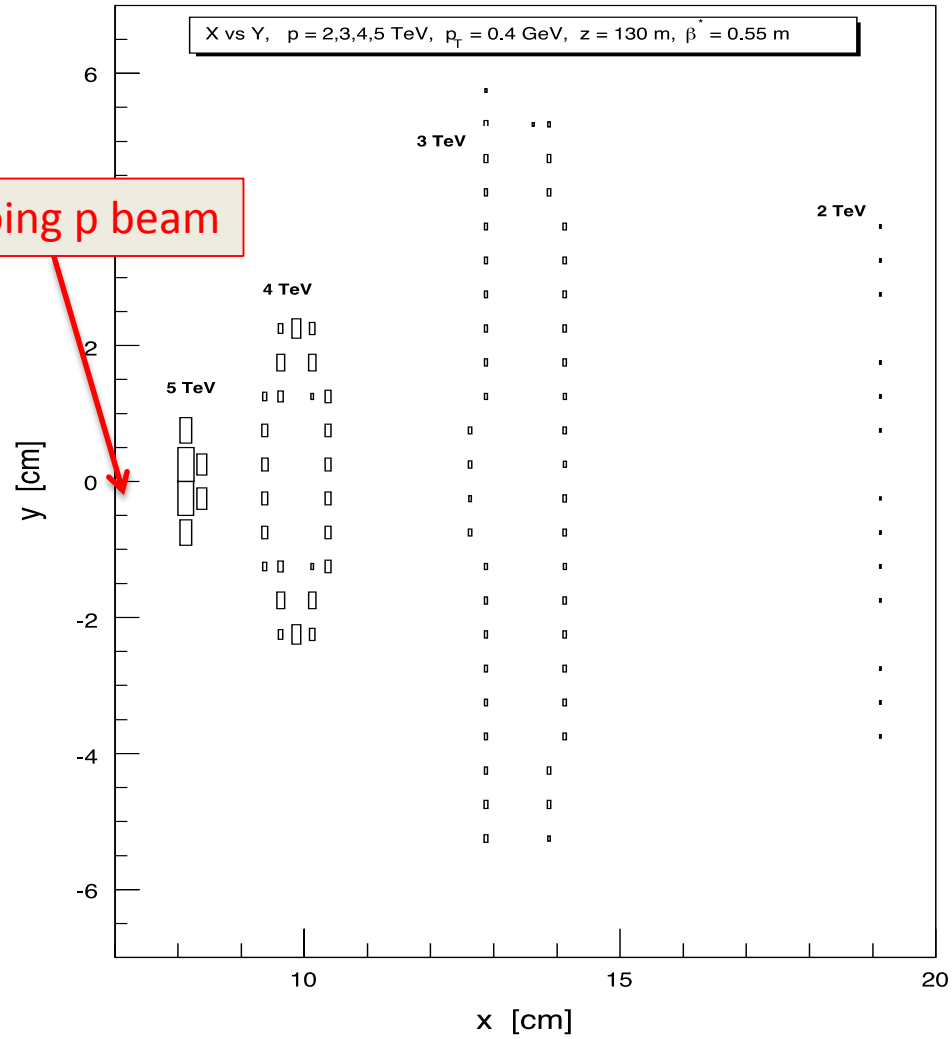
These all exit pipe between 107 and 131 m

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

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

Jerry Lamsa



Outgoing p beam

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.

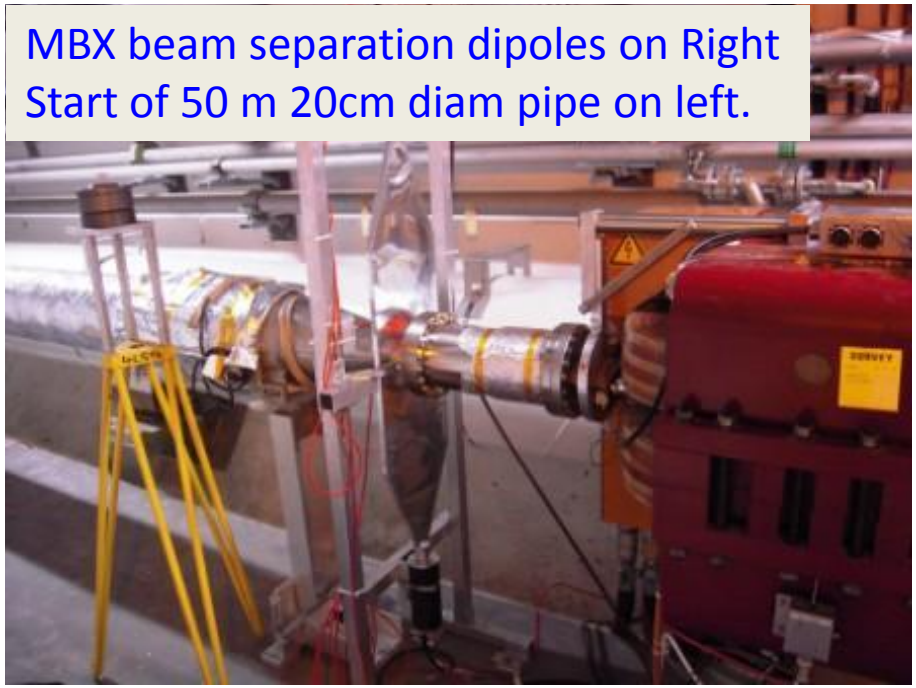
At Pts 2 and 8, larger β* and different, need specific calculations.

Ellipses for p_T = 0.4 GeV/c, all φ.

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

On both sides of Point 5 (CMS) we installed Forward Shower Counters FSC
As “rapidity gap” detectors in low pile-up diffractive collisions.
Simple (scintillators + PMTs) and information limited to showering particles.

MBX beam separation dipoles on Right
Start of 50 m 20cm diam pipe on left.



Half way along, FSC-2.
Concrete shielding walls can be adapted if necessary

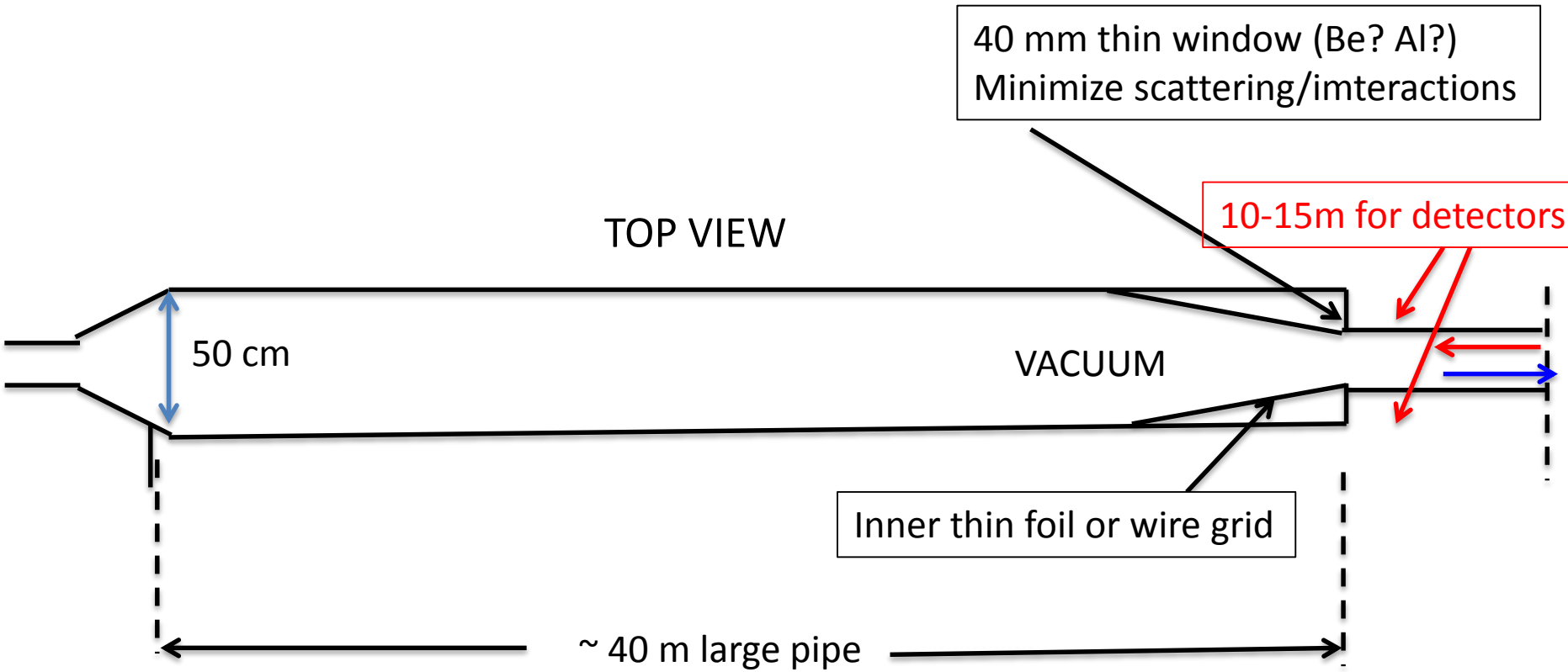
LHCb system “HERSCHEL”
(Paula Collins *inter alia*)

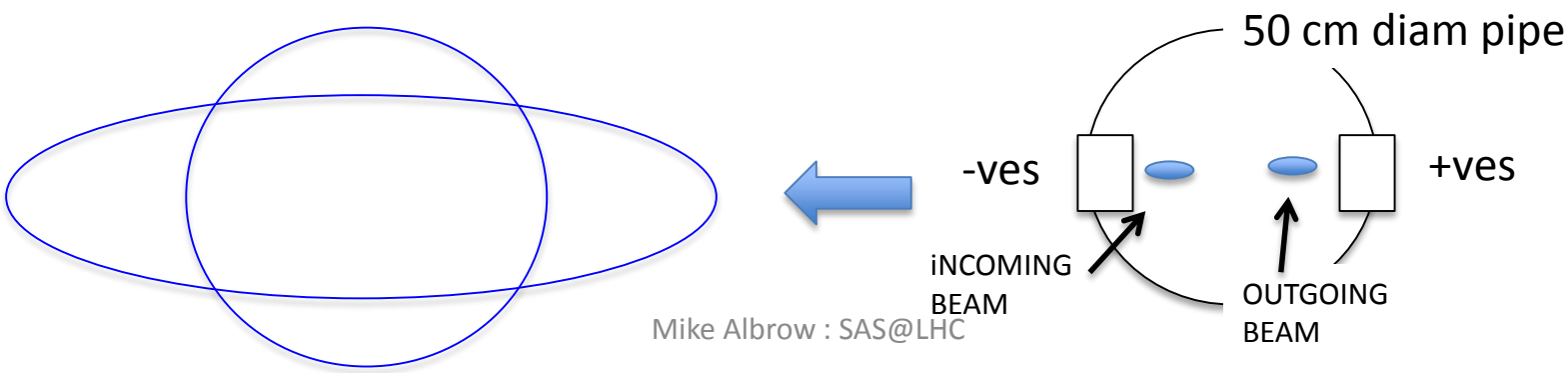
Points 2 (ALICE) AND/OR 8 (LHCb) more appropriate for SAS (than CMS or ATLAS) … Low PU, physics focus, Heavy Ions

Beam pipe design for small angle spectrometer (schematic)

50 cm (?) diameter pipe from 85m to ~ 125m (from collision)

(Jerry Lamsa)



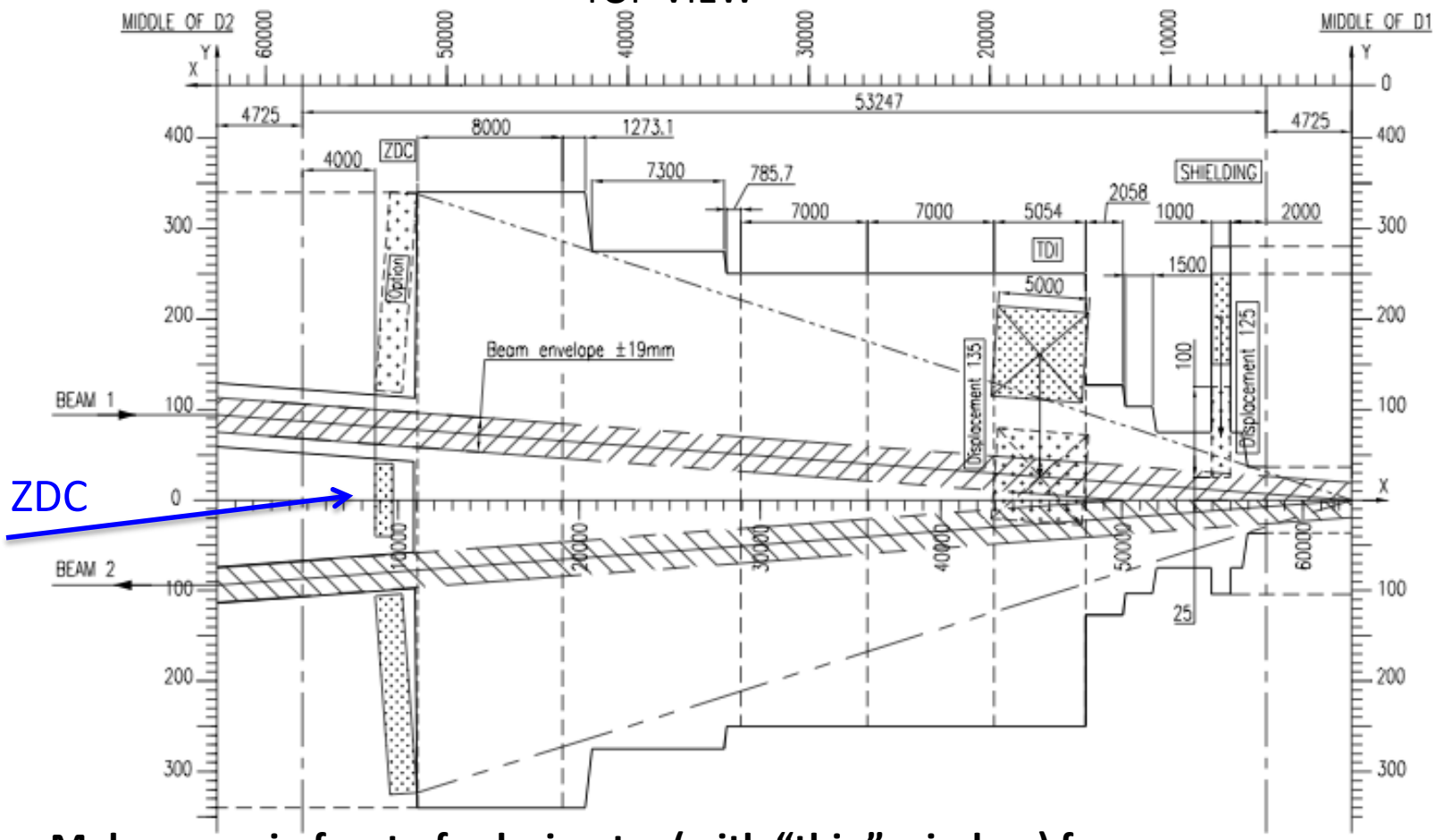


CERN / LHCC 99–5
ALICE TDR 3
5 March 1999

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

ZDC

TOP VIEW



70 cm

ZDC

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

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 … may be small or zero for some particles
But potentially:

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

$K^0_s \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\,\pi$

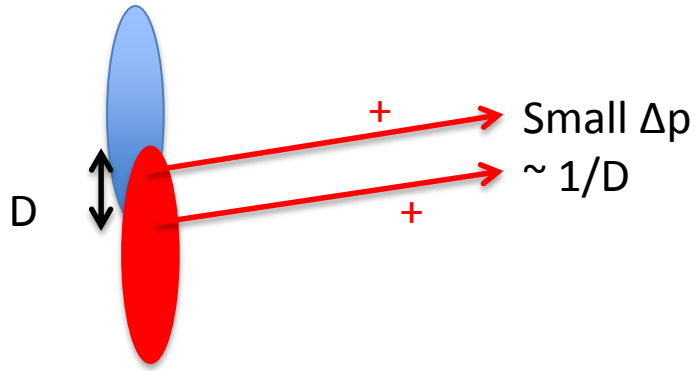
$D^0 \rightarrow K^+\pi^-$ … $\chi_c \rightarrow \pi^+\pi$, K^+K^-, etc.

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

Just a thought:

Bose Einstein Correlations

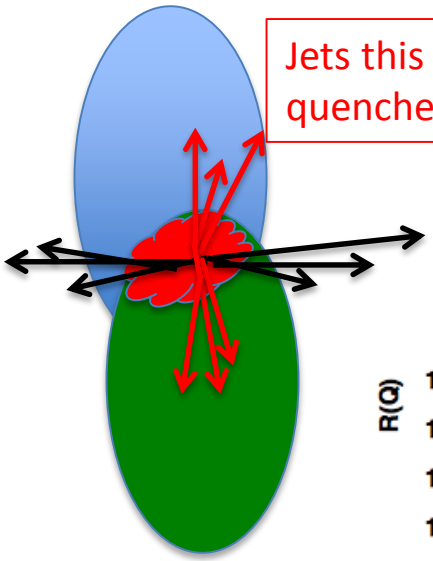
Two same-sign pions (or kaons) close in phase space
Correlation (excess) width → size of emission region
At θ ~ 0 transverse size (overlap)
Interest in heavy-ion collisions … maybe pp too
Correlate with central event.



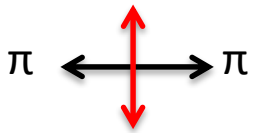
Heavy – ion collisions (ALICE Specialty)

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.
Here just two off “top-of-the-head”:

Head-on view

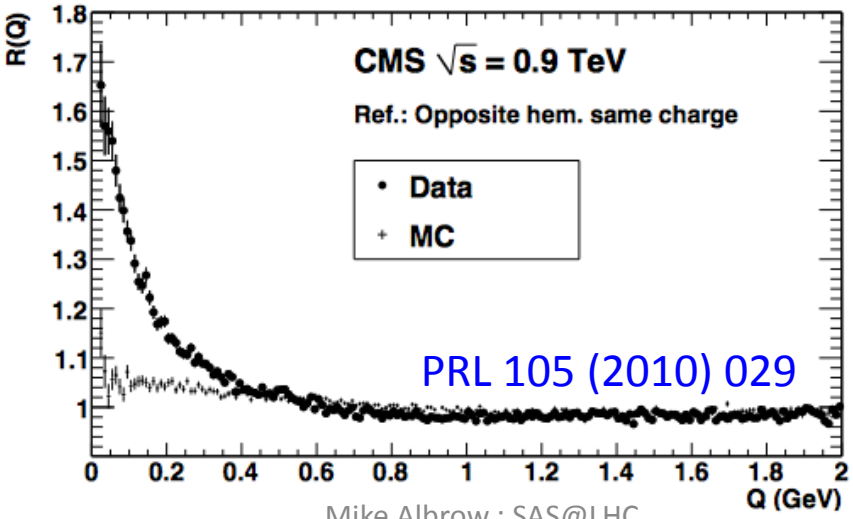


down beam pipe

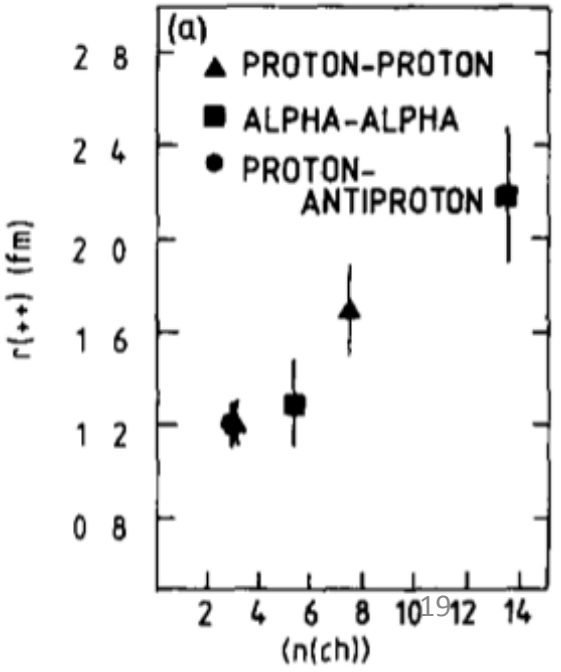


Nuclear fragments:
d, t, He^3, He^4, Li…

Bose-Einstein correlations between π+π+ & π-π- close in momentum measure size of pion emission region.
Directional: correlate with ϕ(jets)



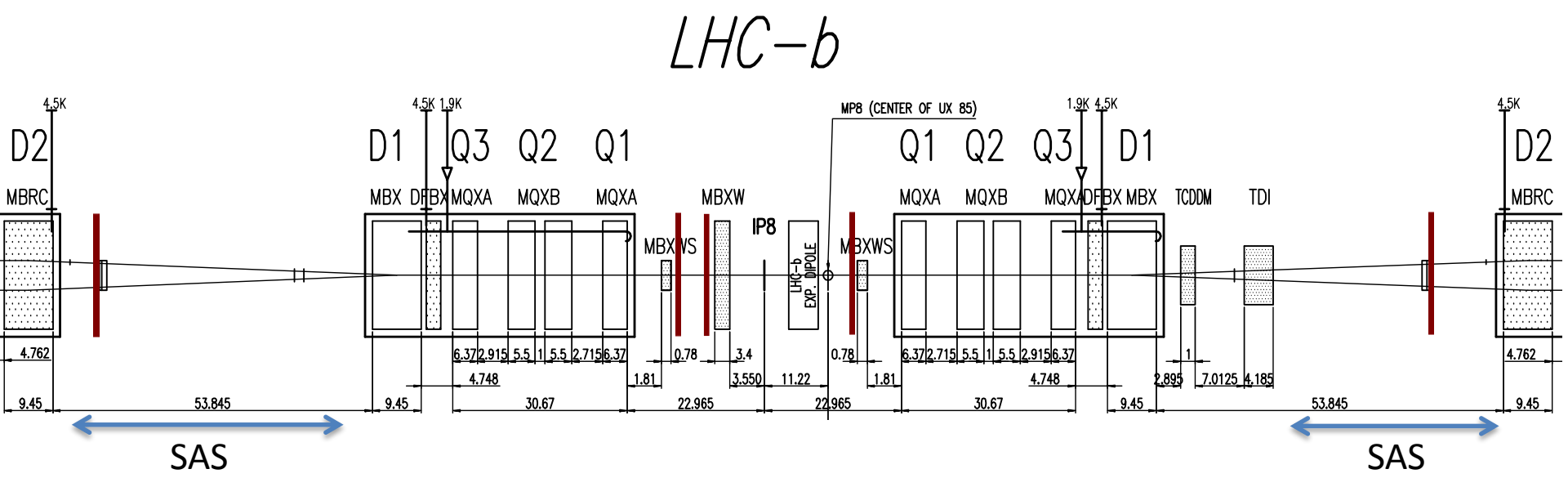
PL 129B (1983) 269 (R807, AFS)



ALICE has pp collisions "for free" for most of the LHC running
Cannot compete with ATLAS and CMS for high mass/high p_T 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 p_T …
Can have unique strong interaction program with SAS (maybe competing with LHCb)

LHCb focus is on charm and beauty, forward (but not ***this*** forward)
Also low PU (good) with β* = 5m (not 0.55m)
SAS extends spectrometer to y ~ 8, 9
Acceptances not yet calculated but will be (Gianluca Cavoto inter alia).



Tracking

Precision tracking immediately behind (thin!) vacuum pipe window (Be?)
No field so straight tracks.

→ x, y, dx/dz, dy/dz at z **σ(x,y) = 10 µm over 2m -> 5 µrad**
Cf bend of 6.5 TeV proton ~ 1500 µrad

$\Theta = 0.3\ B.L(Tm) / p\ (TeV/c)$

Projection of track back → momentum **dp/p < ~ 0.5%** if from primary vertex.

Can be **matched with energy from calorimeter if hadron**
Background from showers in upstream pipe etc. can be reduced or even eliminated.
Tracking measures |Q| also.

i

$[x_0, y_0, z_0, p_x, p_y, p_z]$ at collision $\longleftrightarrow$ $[x, y, \theta_x, \theta_y, E = p]$ at z (Q known)

Tracking is a solved problem, many solutions, much experience

Calorimeters

Wanted for energy measurement
Complements tracks $\Delta p/p \sim 1\%$ if 1^{ry} , and $\Delta E/E \sim 5\%$ probably achievable.
Follow track upstream with p = E to z = 0.
Primaries have x = y = 0 at z = 0, background not.

EM : probably not useful behind TRD (a few X_0 already … TRD as ECAL?)
HADronic sections … can be very deep (even 3m); $\lambda_I(W) = 10$ cm
– good muon filter

Can profit from major developments in high granularity calorimeters
e.g. CMS HGCAL or CALICE (for ILC) types.
But SAS modules much smaller (protoype test module size)

A good hadron calorimeter, compact (tungsten plates) to minimise lateral leakage can be made in ~ 2.5 m of longitudinal space.

If SAS taken up by ALICE or LHCb they already have calorimeters, may “simply add”.

CALORIMETRY for SAS can be done

Muon Measurement behind calorimeter

Muons : from primary collision:

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

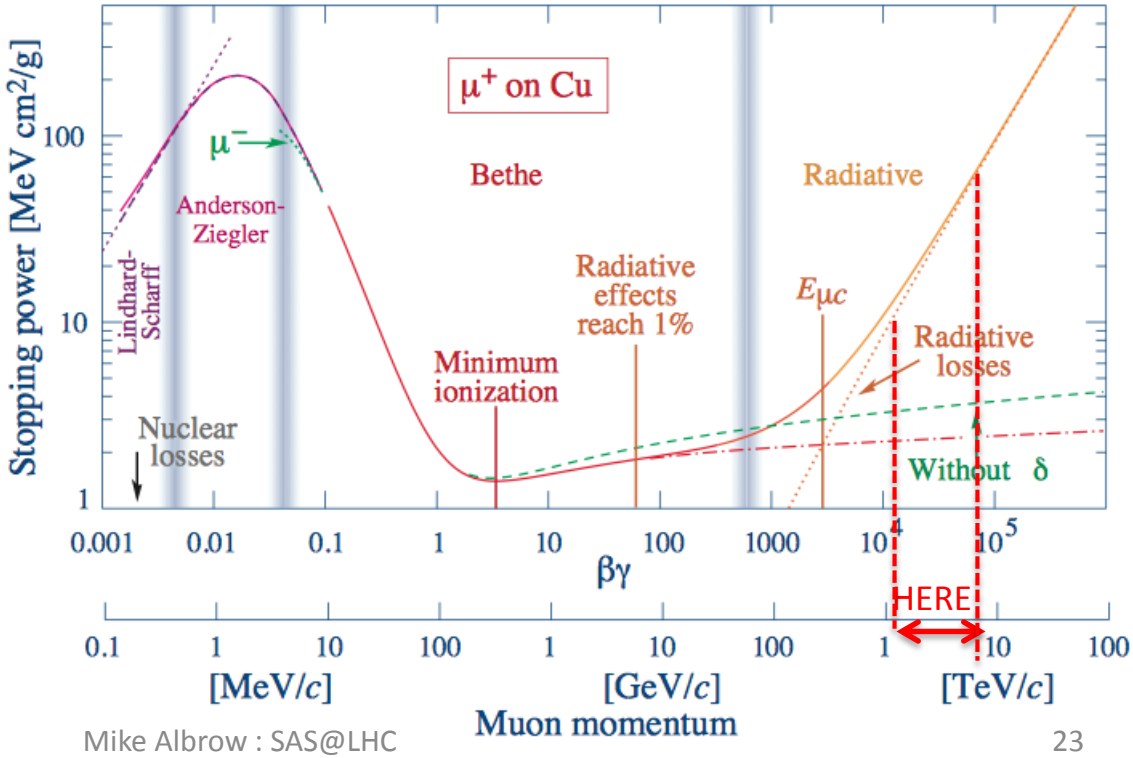
Some acceptance for measuring both! What is it?

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



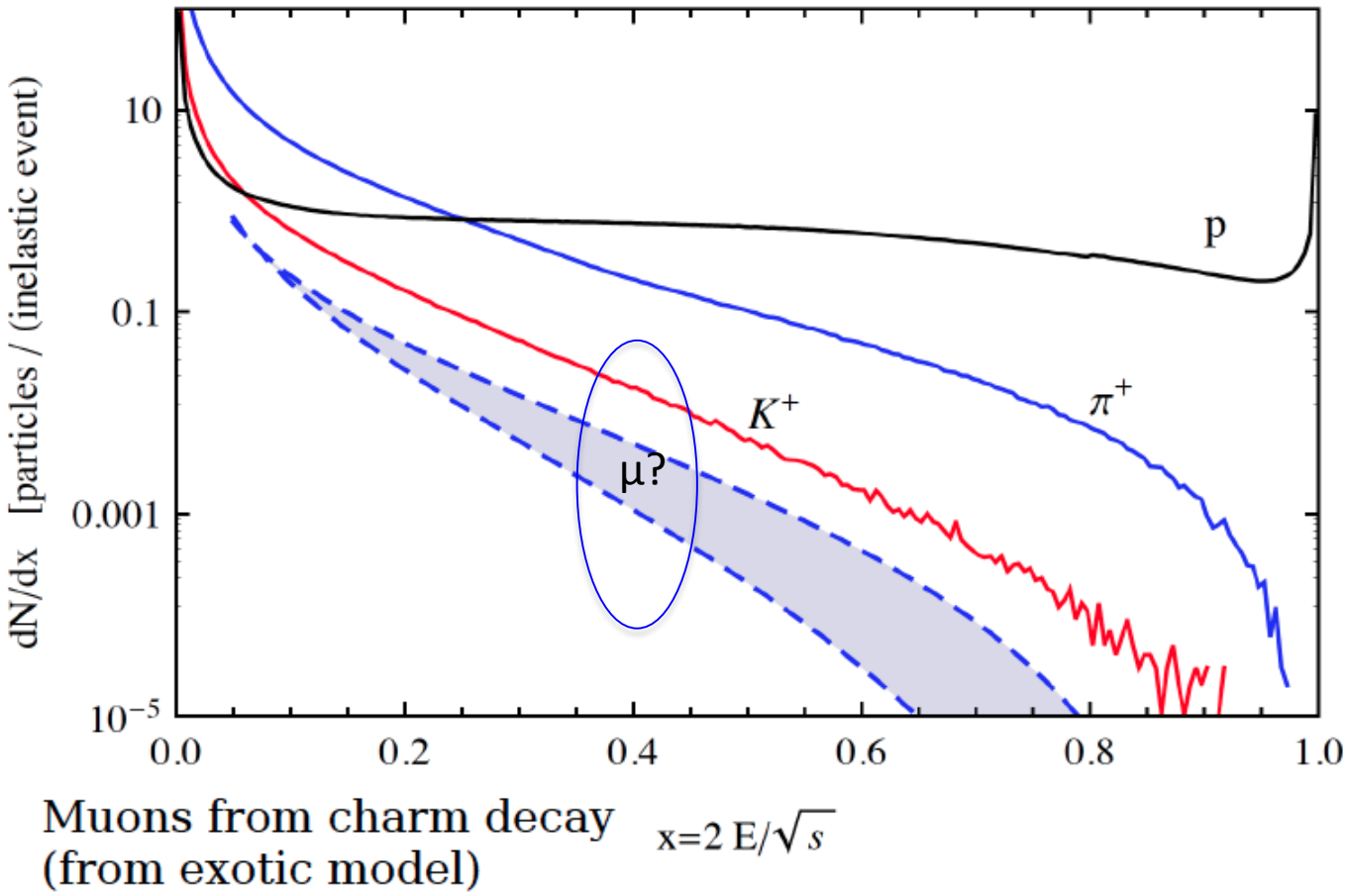
Charm and beauty hadrons only measured at LHC in central region.

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 x_F.

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



Measuring these muons very important for UHE cosmic ray showers and neutrinos

Transition Radiation Detectors - TRD

Probably only technique for distinguishing π / K / p at multi-TeV energies
Interesting challenge far beyond usual e/π separation

Half day parallel session on TRD developments and prospects

2-Day Meeting on SAS@LHC, CERN, Oct 1 + 2

TRD workshop

Conveners: Christoph Rembser (CERN), Anatoli Romaniouk (National Research Nuclear University MEPhI (RU))

Location: 28-S-029

14:00 **Introduction** *10'*
Speaker: Christoph Rembser (CERN)

14:10 **Summary of Graphene radiator studies** *30'*
Speaker: Anatoli Romaniouk (National Research Nuclear University MEPhI (RU))
Graph_TB_summa...

14:40 **GasPixel TRD tests in magnetic field** *20'*
Speaker: Jochen Kaminski (Universitaet Bonn (DE))
GridPix_TRT-TB.pdf

15:00 **Transition radiation from graphene in X-ray domain** *25'*
Speaker: Alexey Tischenko
Tishchenko, CERN...

16:05 **Requirements and general considerations for SAS TRD** *25'*

Speaker: Anatoli Romaniouk (National Research Nuclear University MEPhI (RU))

SAS_TRDs_Gen.pdf

16:30 **Possible configurations for TRD modules for pi/K/p separation in the TeV region** *25'*

Speakers: Paolo Spinelli, Mario Nicola Mazziotta (Universita e INFN, Bari (IT))

TRD - SAS.pptx

16:55 **Straw based and solid state based TRDs for SAS** *25'*

Speaker: Mario Nicola Mazziotta (Universita e INFN, Bari (IT))

NicolaM_1Oct2015...

17:20 **Preliminary TRD simulations for Forward Scattering Experiment** *25'*

Speaker: Michael Cherry (Louisiana State University)

SAS_CERN_Oct_20... SAS_CERN_Oct_20...

17:45 **Gas pixel TRD - what they can do?** *25'*

Speaker: Anatoli Romaniouk (National Research Nuclear University MEPhI (RU))

GasPixel_TRDs.pdf GasPixel_TRDs.ppt

18:10 **Discussion of the TRD concepts for SAS** *45'*

Speaker: ALL

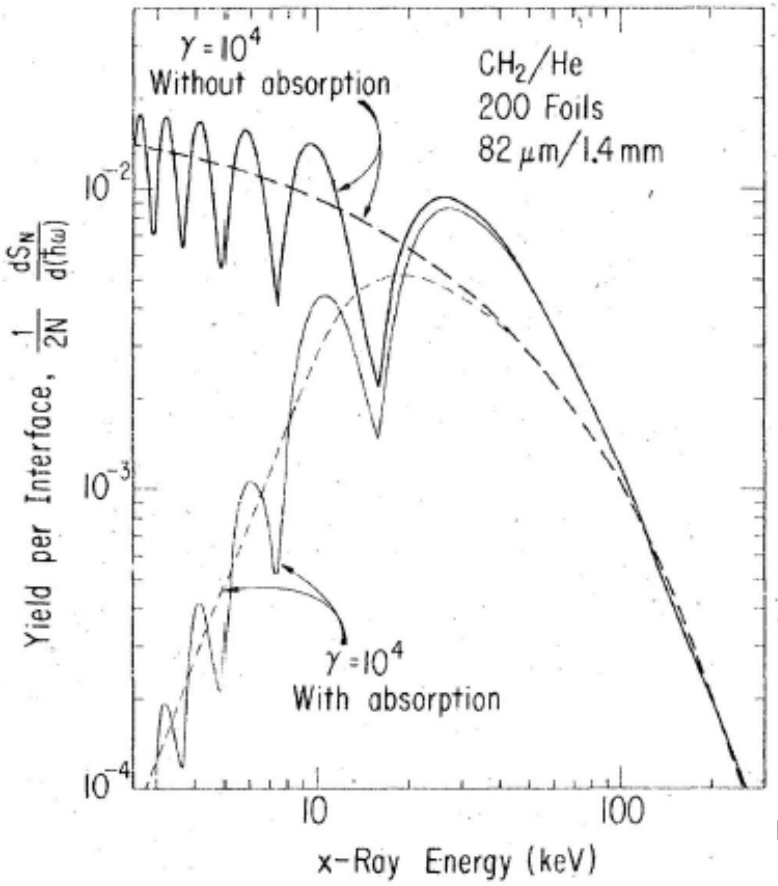
Technical challenge: Identification of multi-TeV π/K/p

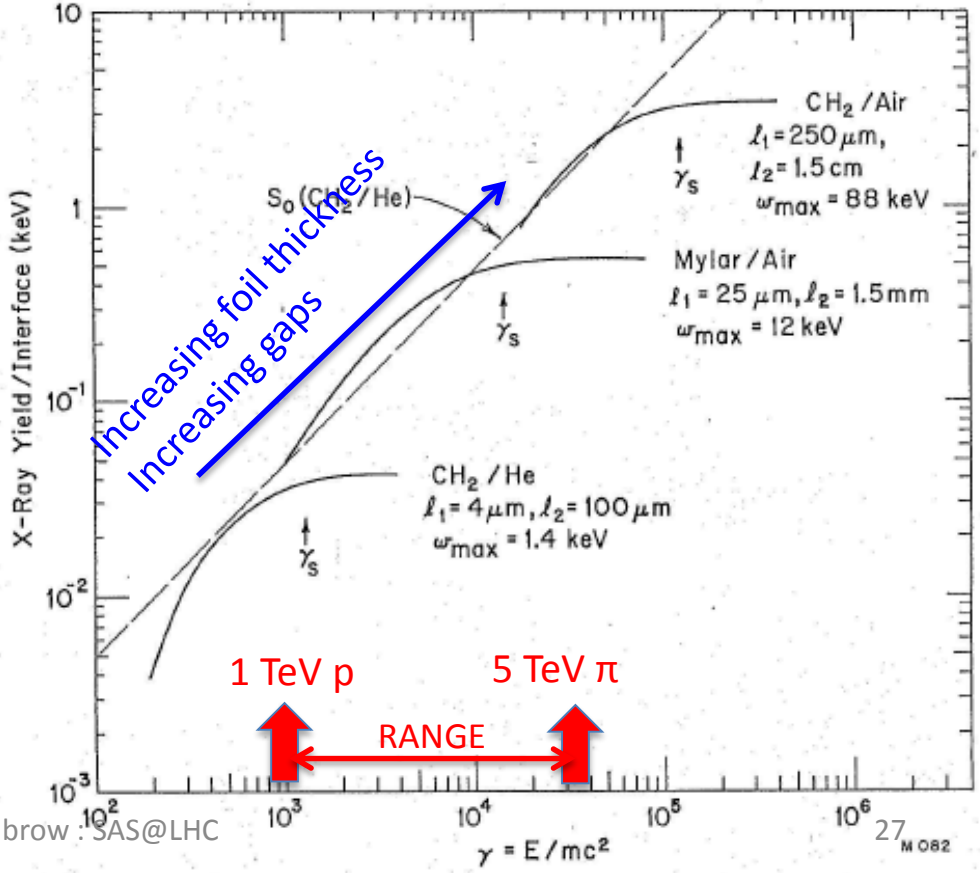
Mike Cherry

Cherenkov counter cannot as "β = 0.99..999" for all.
Only game in town: Transition Radiation Detectors TRD
Interface between two materials different ε → X-ray emission ~ 1/137 but prop-to γ = E/m
Know E = p from tracking and calorimeter, hence m.
Fastest hadrons in SAS ~ 5 TeV π; γ = 5000/0.14 ~ 3.6 10^4
Slowest in SAS ~ 1 TeV p; γ = 1000/0.94 ~ 1.1 10^3

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

In PDG





Identification of π/K/p : Main technology challenge! (Crystals are too)

Transition radiation at interfaces between

Materials of different dielectric constant measure γ = E/m (E from calorimeter)

10 % measurement of γ with 5% measurement of E → good separation

Dolgoshein

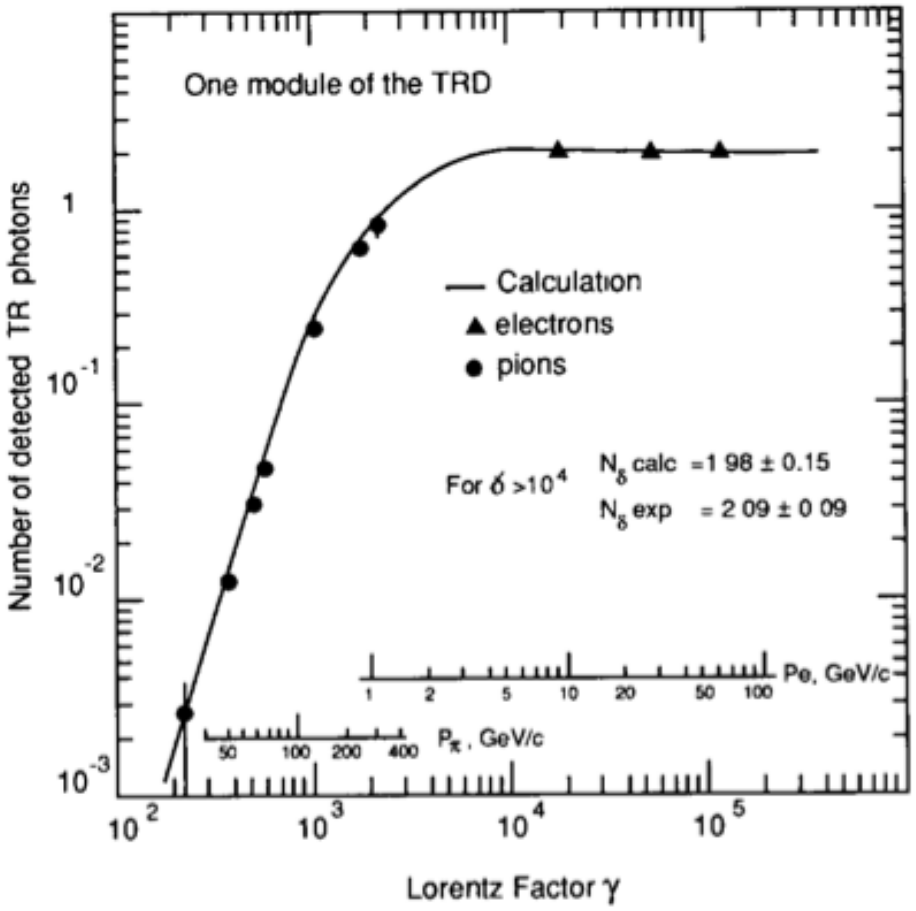
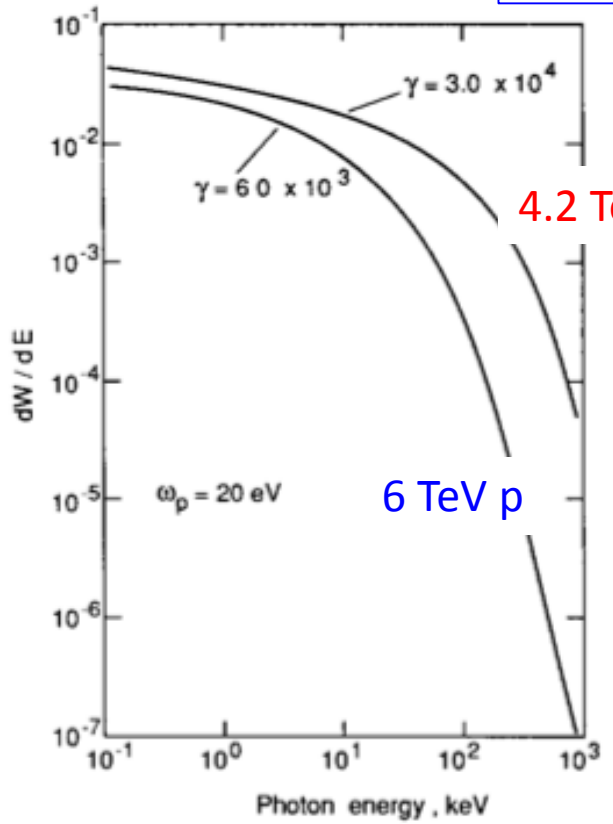


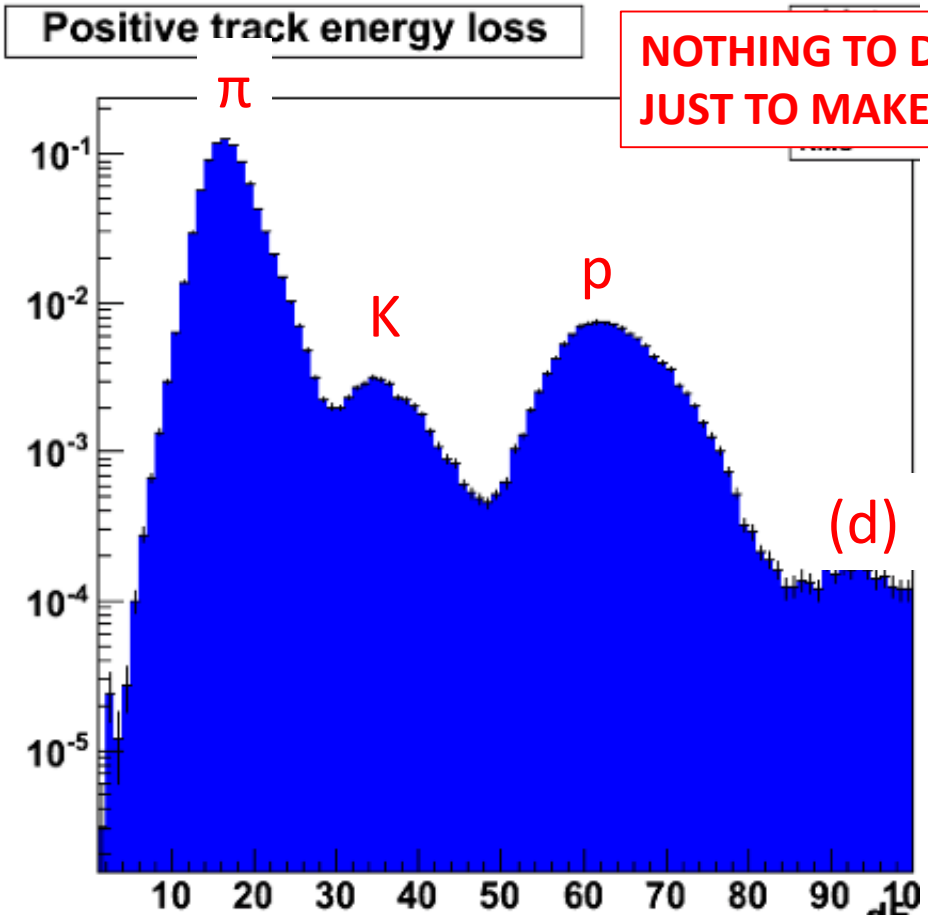
Fig. 12. Comparison of the detected number of TR photons with MC calculation for various γ-values (TR radiator: CH_2 foils).



3. The radiated TR spectrum from a polyethylene sur face.

Mike Cherry

Note: To measure single hadron inclusive spectra do not need 5%/10% separation!
Example from CDF Drift chambers of dE/dx ionization measurement in one p-bin (400 MeV/c)



NOTHING TO DO WITH TRD!
JUST TO MAKE A POINT

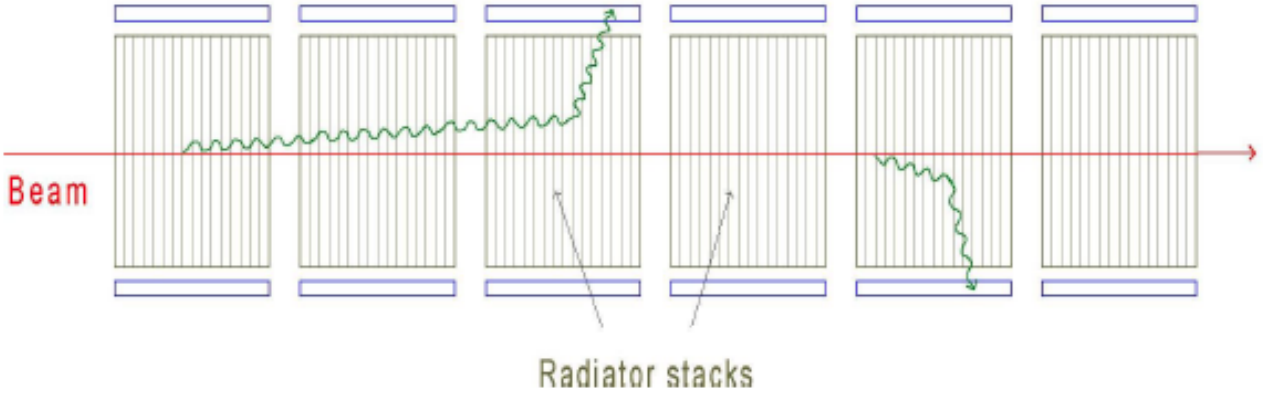
Fit → composition for
all p-bins → spectra.
(Also pile-up irrelevant.)

Better separation needed to
do correlations e.g. M(Kπ) … D0?
and with central event, e.g. :

TRDs in SAS, like other detectors, accessible and replaceable as improved

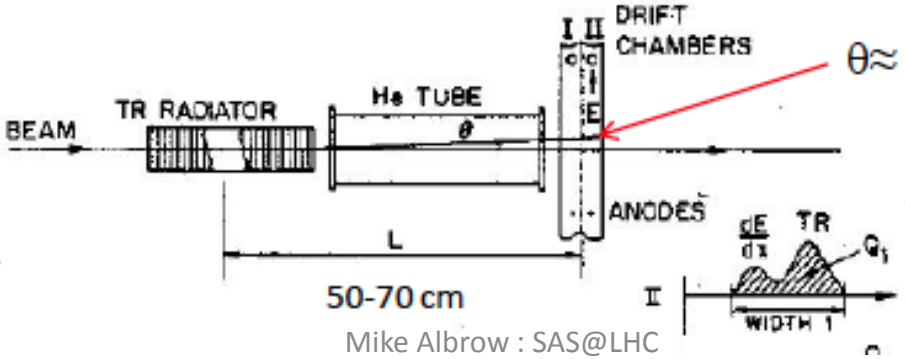
In principle can also detect Compton scattered X-rays on sides of radiator stack:

Compton scatter configuration – CERN test w/Al honeycomb, NaI



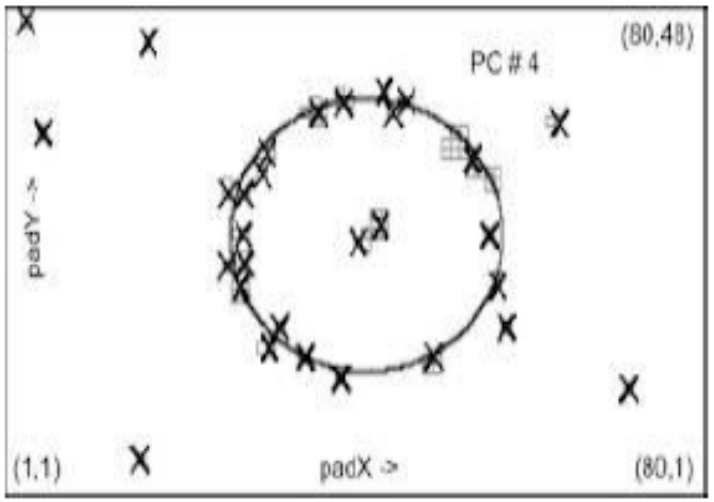
Another old idea, now perhaps feasible with new detectors (e.g. micromegas):

M.Deutschmann et al.
Partice identification using the angular distribution of transition radiation
N.I.M. 180 (1981) 409-412



$\theta \approx 1/\gamma \rightarrow \Delta x \approx 0.1\text{–}1$ mm
for γ = 10.000 -1000
beware: $\theta_{\text{mult. scatt.}}$?

Mike Cherry



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 traking information!

-the momenta , namely the rings radii per each kind of particle, are fixed by the calorimeter: 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

Acceptance for higher x_F ~ 0.7 – 0.9
Bent crystal channeling

Large area of research, annual international conferences etc.

Needed to cover x_F > ~ 0.8 – 0.9 region, otherwise down beam pipe.
Intercept particles close to beam at around 90m
with long (~ 12 cm?) crystal with 4 – 5 mrad deflection.

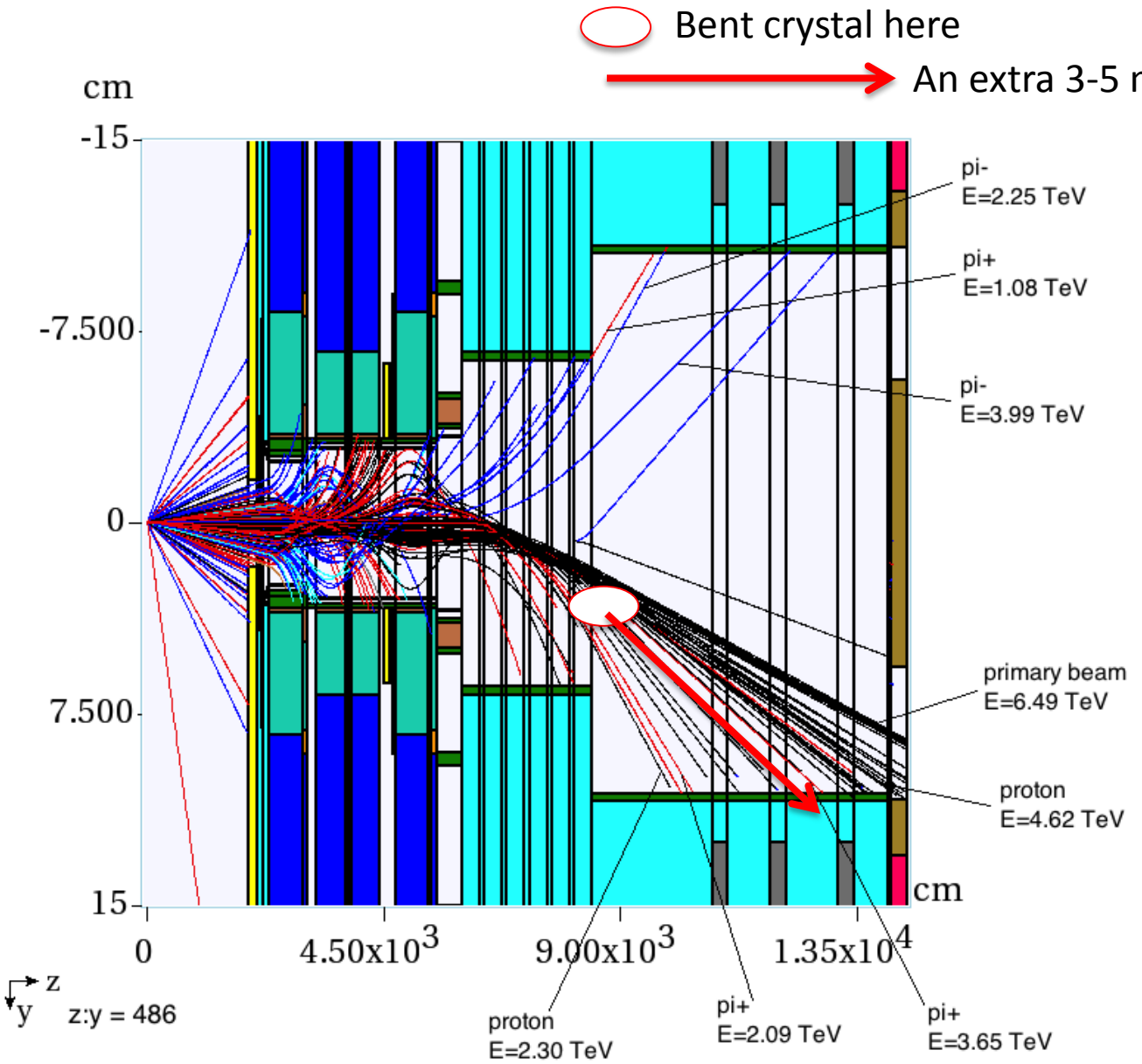
Inside vacuum chamber, position and angle steering.

Developments over years, for beam collimation and also extraction (AFTER)
In principle : SAS → study interactions of TeV identified mesons.

UA9 Experiments

W.Scandale, G.Cavoto *inter alia* (UA9 collaboration … tests in SPS, LHC)

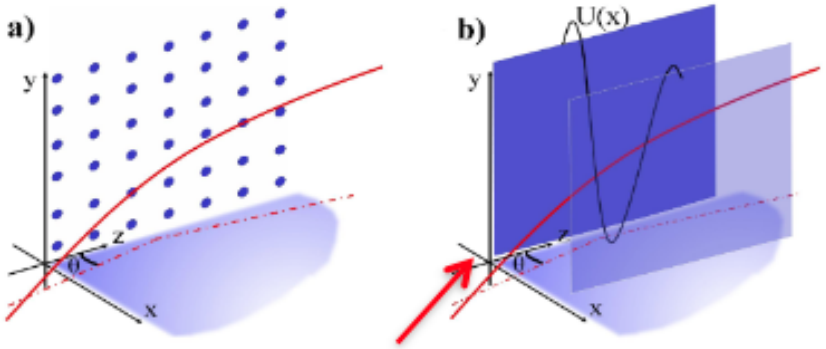
Protons probably > 99% at x_F = 0.9 .
Into diffractive proton region for high mass *and* high-t (acceptance?)
Study heavy flavors in high-mass diffraction e.g. in central detector.
(Low mass diffraction e.g. p → p π+π- may be studied inside SAS)
And rarest high-x mesons *may* be most interesting!



Pipe shown at 10 cm radius (as now at Pt.5) but will be larger (~ 25 cm?)

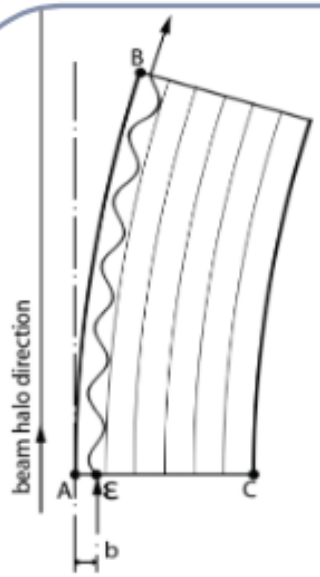
Extension of x_F acceptance towards x_F ~ 0.9 (or more?)

Crystal channeling, a coherent interaction



Charged particle direction within a **critical angle** relative to the atomic planes.

Trapped in the lattice electric potential U(x).



If crystal mechanically **bent**,

particles still oscillate inside the "channel".

Particles emerge **deflected** and **parallel** **(low divergence)**.

Critical angle

$$\theta_C = \sqrt{\frac{2U_0}{E}}$$

Potential well depth ~Z [22.7 eV for (110) Si]

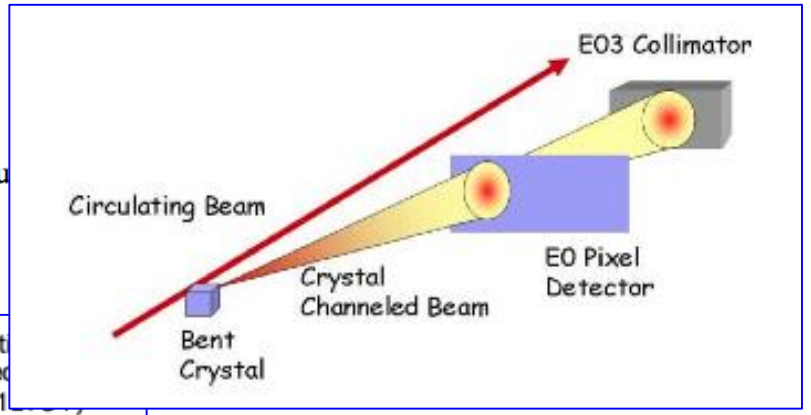
Particle energy

$\theta_C \approx 20\,\mu rad$ at $E \sim 100$ GeV

RECENT T980 CRYSTAL COLLIMATION STUDIES AT THE TEVATRON EXPLOITING A PIXEL DETECTOR SYSTEM AND A MULTI-STRIP CRYSTAL ARRAY*

D. Still[+], G.E. Annala, R. A. Carrigan, A.I. Drozhdin , T.R. Johnson, N. V. Mokhov, V. Previtali ,
R. Rivera, V. Shiltsev, J. Zagel, Fermilab, Batavia, IL 60510, U.S.A.
V.V. Zvoda, NIU, DeKalb, IL 60510, U.S.A.
D. Mirarchi, S. Redaelli, CERN, CH-1211, Geneve 23, Switzerland
V. Guidi, A. Mazzolari, INFN-Ferrara, Italy
Y.M. Ivanov, PNPI, Gatchina, Leningrad Region, RU-188300, Russia
Y.A. Chesnokov, I.A. Yazynin, IHEP, Protvino, Moscow Region, RU-142284, Ru

Channeling 980 GeV beam!



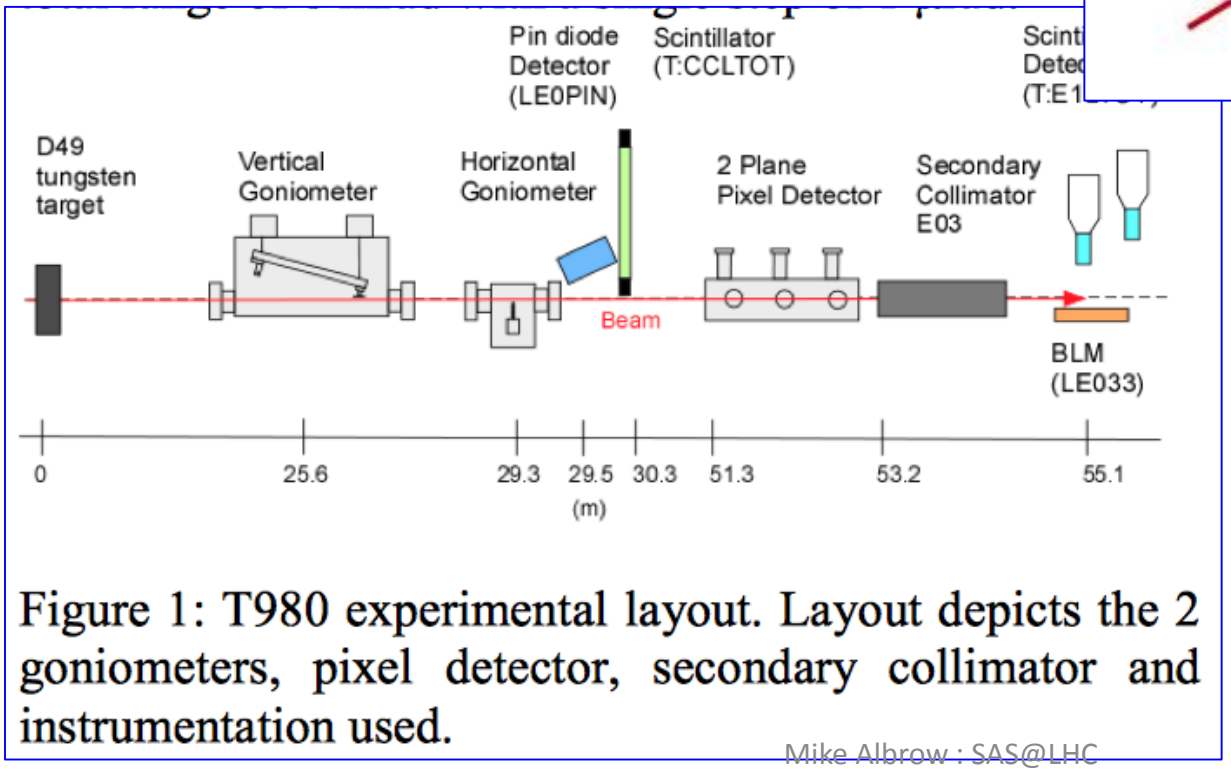
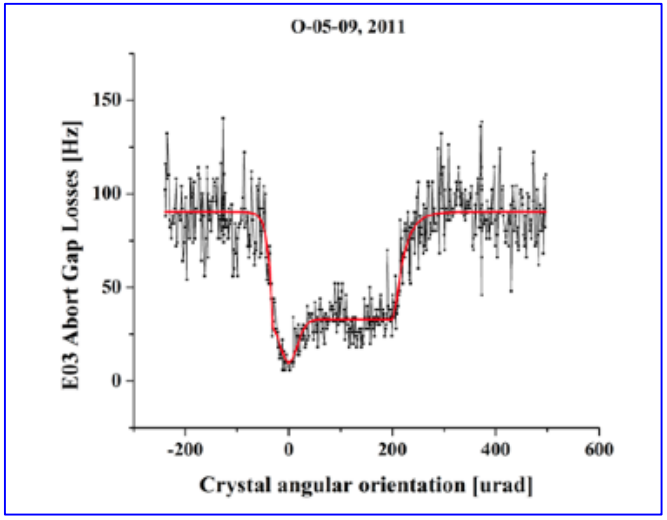


Figure 1: T980 experimental layout. Layout depicts the 2 goniometers, pixel detector, secondary collimator and instrumentation used.



The RD22 Collaboration, CERN DRDC 94-11 1994

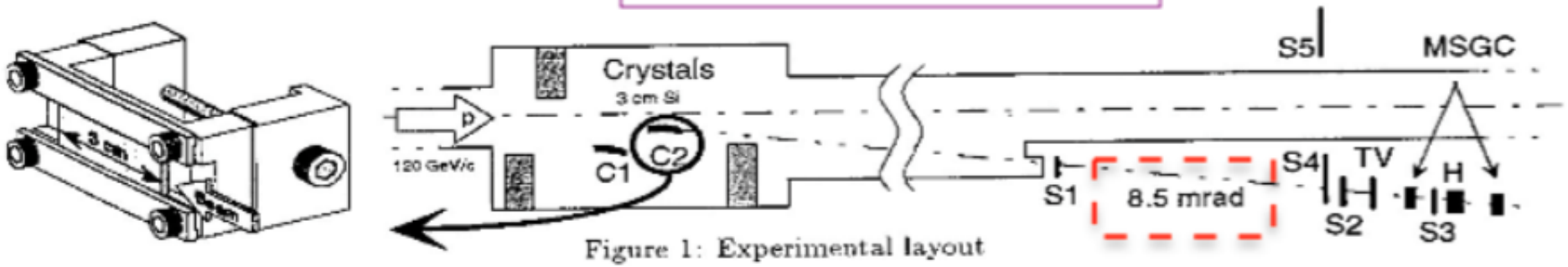
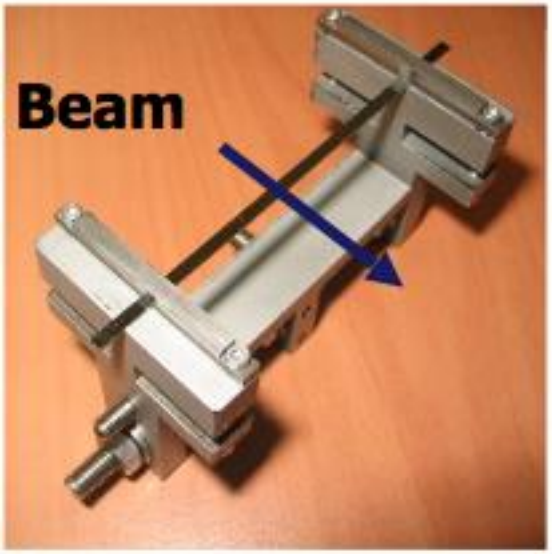


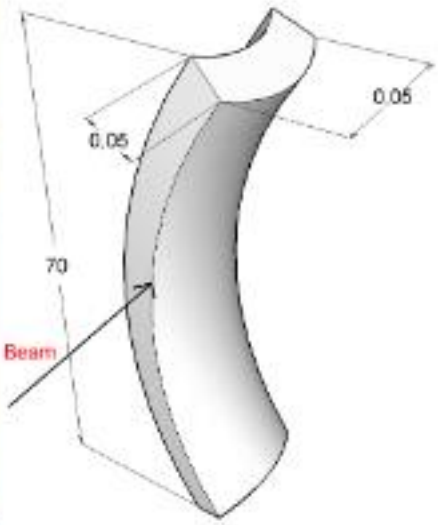
Figure 1: Experimental layout

Interaction with SAS

- UA9 **test facilities** have guaranteed a high standard of crystal validation and test.
  - Necessary **procedures** to install other crystals in to the LHC.
- Actively working on special crystals (dedicated ERC grant *CRYSBEAM*) to get **large bending angles** at the highest energy.
- If crystal is a part of SAS, measurement of **channeling efficiency at 6.5 TeV** is a key element to measure **cross-sections**

Gianluca Cavoto (INFN Roma)





UA9 is an on-going project studying beam halo collimation and extraction, in SPS and in 2016 inside LHC beam pipe.

Use for SAS interesting, challenge

"Anticlastic bending" of crystal.

Photo of SPS pipe assembly

Goniometers inside LHC vacuum pipe
Move in x, y, θx, θy to cover phase space
Acceptance very small (µrad)
Deflection angles ~ 1 mrad OK, 4-5 mrad?
Several in series possible.
Positive particles only channeled.
No change in |p|, only angle.

Gianluca Cavoto (INFN Roma)

Summary

Terra Incognita : large phase space (in x_F, p_T) unexplored from √s = 63 – 13,000 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

Spectrometer magnets and 85m vacuum chamber + 55m straight section exist.
Need **special vacuum chamber** with thin exit windows. Feasible.
Technology for **tracking, calorimeter, muon** tracking exist, small area & can use the best!
Particle ID with **transition radiation** possible (π,K,p) … interesting challenge to improve.
Bent **crystal channeling** to extend x_F – coverage possible … interesting challenge to improve.
Open & accessible & small so evolution of techniques natural.

How and where?
Want many months of running with low pile-up: Pt.1 (ATLAS) and Pt.5(CMS) not good.
Pt.8 (**ALICE**) and Pt.2 (**LHCb**) have best conditions and better alignment with physics.
Both should find addition of SAS enhances their physics program, both pp and nuclei
Or : **Independent new** experiment (expect later merger)
In any case : TRD experts will develop suitable TR detectors
Crystal channeling experts are developing Xtals.
A milestone: Workshop in May, Italy on forward physics at LHC

It should be done and it can be done!

Thank You

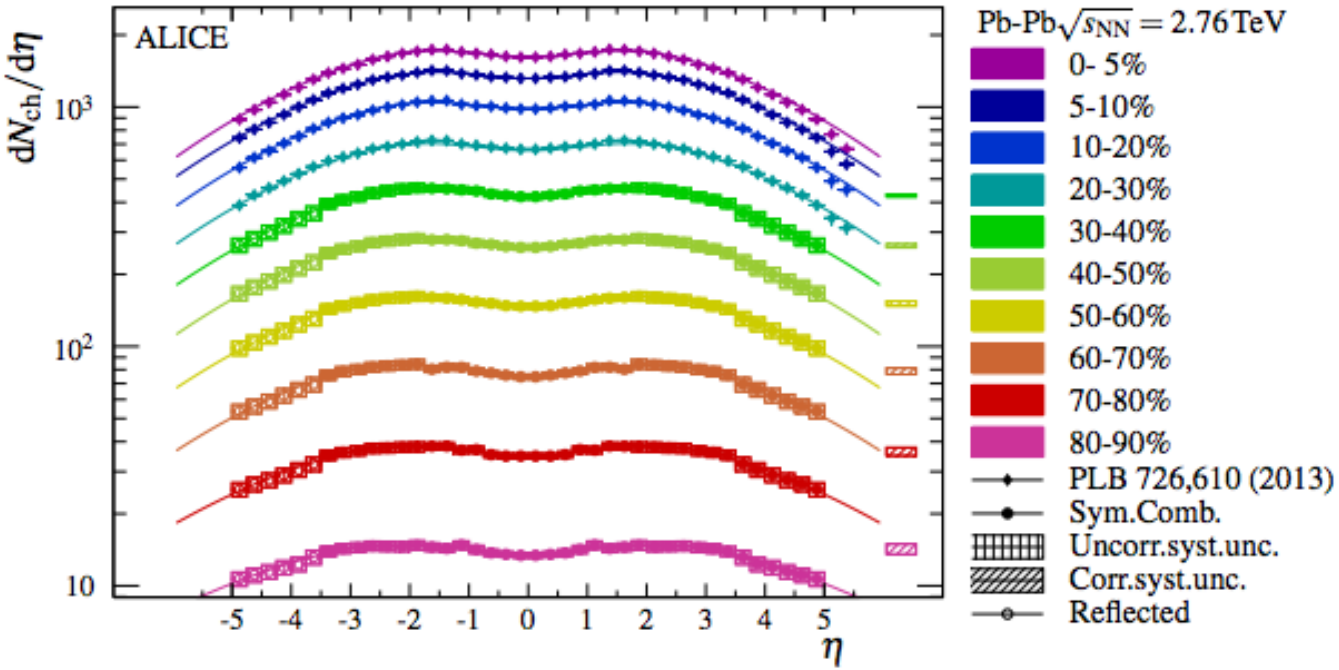
Back Ups →

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



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

Agenda: Thursday morning plenary. Meeting : informal, discussions

Thursday, 1 October 2015

09:00 - 13:00 **Plenary** Join Salle Anderson

Convener: Michael Albrow (Fermi National Accelerator Lab. (US))

Location: 40-S2-A01 - Salle Anderson

09:00 **Welcome and Introduction** *20'*
Speaker: Michael Albrow (Fermi National Accelerator Lab. (US))

09:20 **Physics of forward particle production; event generators** *30'* No speaker?

09:50 **Cosmic ray showers and need for SAS** *30'*
Speaker: Paolo Lipari

10:20 **Coffee** *15'*

10:35 **Zero-degree neutral (n, K0, π0,...) measurements at LHC** *30'*
Speaker: Alessia Tricomi (Universita e INFN, Catania (IT))

11:05 **Studies towards the design of a Small Angle Spectrometer at the LHC** *25'*
Speaker: Ottavio Fornieri (Pisa)

11:30 **Particle optics and large pipe** *20'*
Speaker: Jerry Lamsa (Iowa State University (US)) (probably not)

12:10 **LHC Vacuum pipe and window issues** *30'*
Speaker: Benoit Salvant (CERN)

Thursday afternoon parallel session

14:00 - 17:30 **SAS calorimeter & Tracking**

Join

Convener: Michael Albrow (Fermi National Accelerator Lab. (US))

Location: 60-2-023

14:00 **High Granularity calorimeter (HGCAL) for CMS upgrade** *30'*
Speaker: Slawomir Marek Tkaczyk (Fermi National Accelerator Lab. (US))

14:30 **Test beam experiments with the CALICE scintillator tungsten HCAL** *30'*
Speaker: Eva Sicking (CERN)

15:00 **CT-PPS Tracking for SAS@LHC TBC** *20'*
Speaker: Nicolo Cartiglia (Universita e INFN Torino (IT))

15:20 **Muon track detection** *20'*
Speaker: Michael Albrow (Fermi National Accelerator Lab. (US))

15:40 **Discussion** *30'*
Speaker: All

Parallel Session: Workshop on TRDs for SAS

14:00 - 19:00 **TRD workshop**

Join 28-S-029

Conveners: Christoph Rembser (CERN), Anatoli Romaniouk (National Research Nuclear University MEPhI (RU))

Location: 28-S-029

14:00 **Introduction** *10'*
Speaker: Christoph Rembser (CERN)

14:10 **Summary of Graphene radiator studies** *30'*
Speaker: Anatoli Romaniouk (National Research Nuclear University MEPhI (RU))

14:40 **GasPixel TRD tests in magnetic field** *20'*
Speaker: Jochen Kaminski (Universitaet Bonn (DE))

15:00 **Transition radiation from graphene in X-ray domain** *25'*
Speaker: Alexey Tischenko

15:25 **Discussion&future plans** *20'*
Speaker: ALL

15:45 **Coffee** *20'*

16:05 **Requirements and general considerations for SAS TRD** *25'*
Speaker: Anatoli Romaniouk (National Research Nuclear University MEPhI (RU))

16:30 **Possible configurations for TRD modules for pi/K/p separation in the TeV region** *25*
Speaker: Paolo Spinelli

16:55 **Straw based and solid state based TRDs for SAS** *25'*
Speaker: Mario Nicola Mazziotta (Universita e INFN, Bari (IT))

17:20 **Preliminary TRD simulations for Forward Scattering Experiment** *25'*
Speaker: Michael Cherry (Louisiana State University)

17:45 **Gas pixel TRD - what they can do?** *25'*
Speaker: Anatoli Romaniouk (National Research Nuclear University MEPhI (RU))

18:10 **Discussion of the TRD concepts for SAS** *45'*
Speaker: ALL

Friday Oct 2nd Plenary

09:05 **Channeling for high-xF** *30'*
Speaker: Gianluca Cavoto (Universita e INFN, Roma I (IT))
crystal channeling

09:35 **Transition radiation summary report & plans** *40'*
Speaker: Michael Cherry (Louisiana State University)
SAS_CERN_Oct_20... SAS_CERN_Oct_20...

10:20 **Calorimeter summary report** *20'*
Speaker: Michael Albrow (Fermi National Accelerator Lab. (US))
calo-trk summary.... calo-trk summary....

10:40 **Coffee Break** *20'*

11:00 **LHCb very forward detectors** *30'*
Speaker: Paula Collins (CERN)
FSC_LHCb.pdf

11:30 **SAS at ALICE** *30'*
Speaker: Risto Orava (Helsinki Institute of Physics (FI))
ALICEZDC-worksh...

12:00 **Acceptance, rates, running conditions** *20'*
Speaker: ALL

Regular meetings to develop plans. → Workshop on Forward LHC Physics, Italy in May
Stand-alone ::: ALICE extension ::: LHCb extension ?? (Effort, money, politics, …)