Small Angle Spectrometers at LHC : First meeting
CERN Oct 1st & 2nd

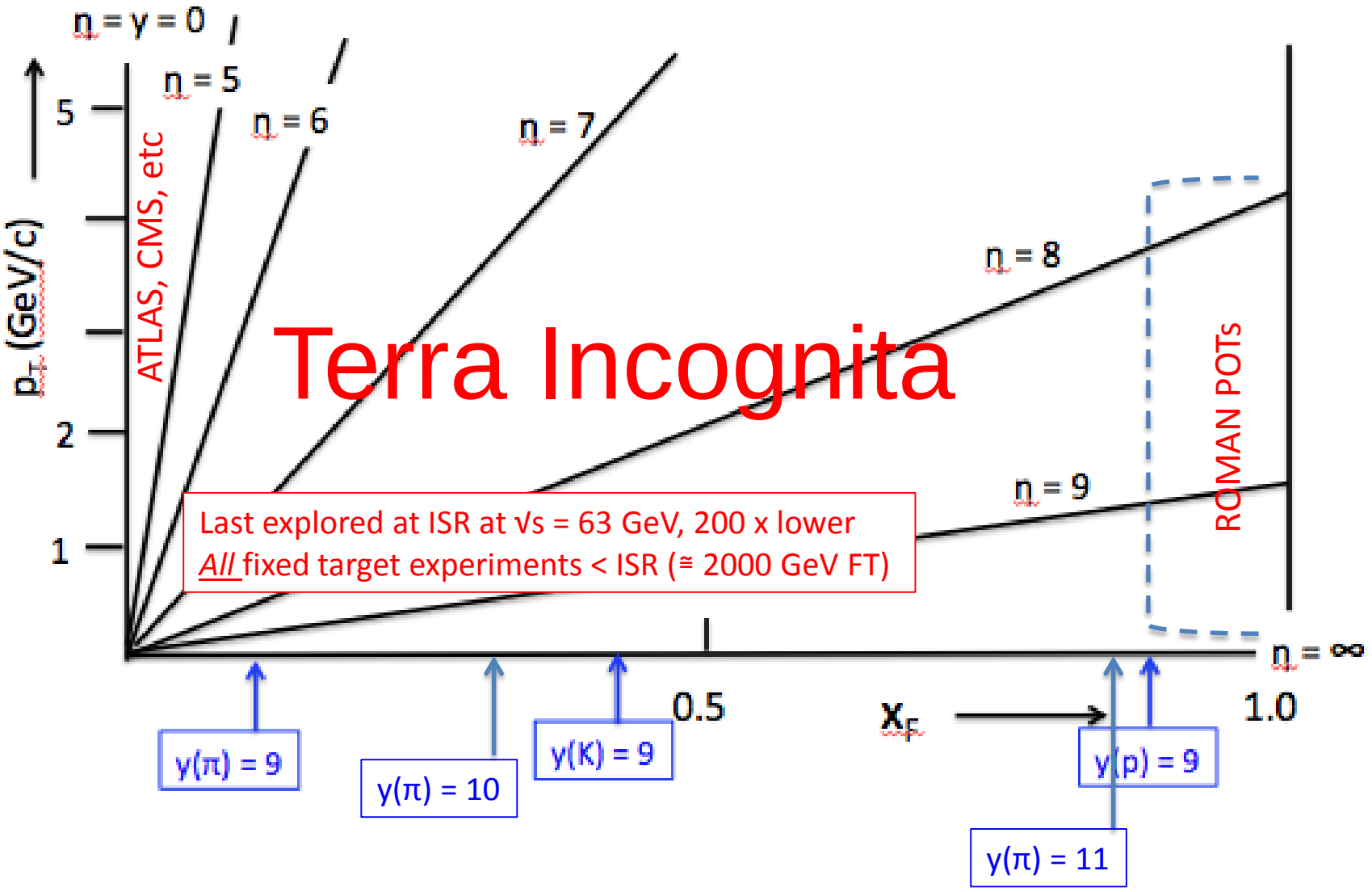
Charged particles produced in hadron hadron colliders with Feynman-x = 0.1 – 0.9
have not been measured above √s = 63 GeV (ISR, 1970's) Now we are 200 x higher!
Even |η| = 5 is "central" in Feynman-x terms.
Roman pots measure protons (dominant) with $x_F > 0.9$ (diffractive and elastic)
ZDC, LHCf measure neutrals (n, $\pi^0 \rightarrow \gamma\gamma$) at very small angles.
Charged particle spectra will be very different. **New window on strong interactions**

Cosmic ray showers in atmosphere depend on these spectra. E(equiv) ~ 10^{17} eV
Different models of particle production diverge at high energy, data can improve situation
>> Talk by P. Lipari

Idea, using perhaps 10 – 15 m of space in front of TAN:
Use **MBX dipoles** (Integral B.dL = 30 - 36 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 (Salvant)
Precision tracking (silicon strips or pixels) over a few m (θx, θy to a few μrad)
Transition Radiation Detectors for γ = E/m in 10^4 – 10^5 region
Calorimeter (EM + HAD) for Energy measurement (Slawek Tkaczyk and Eva Sicking this pm)
Muon tracking behind Calorimeter
Bent crystal to channel and so accept highest momenta (>~ 4.5 TeV, 5 mrad bend)

x_F at $p_T = 0$ and true rapidity y = 9 shown for at √s = 13 TeV

x_F (at $p_T = 0$) = $m.e^y/\sqrt{2}.p_{beam}$)

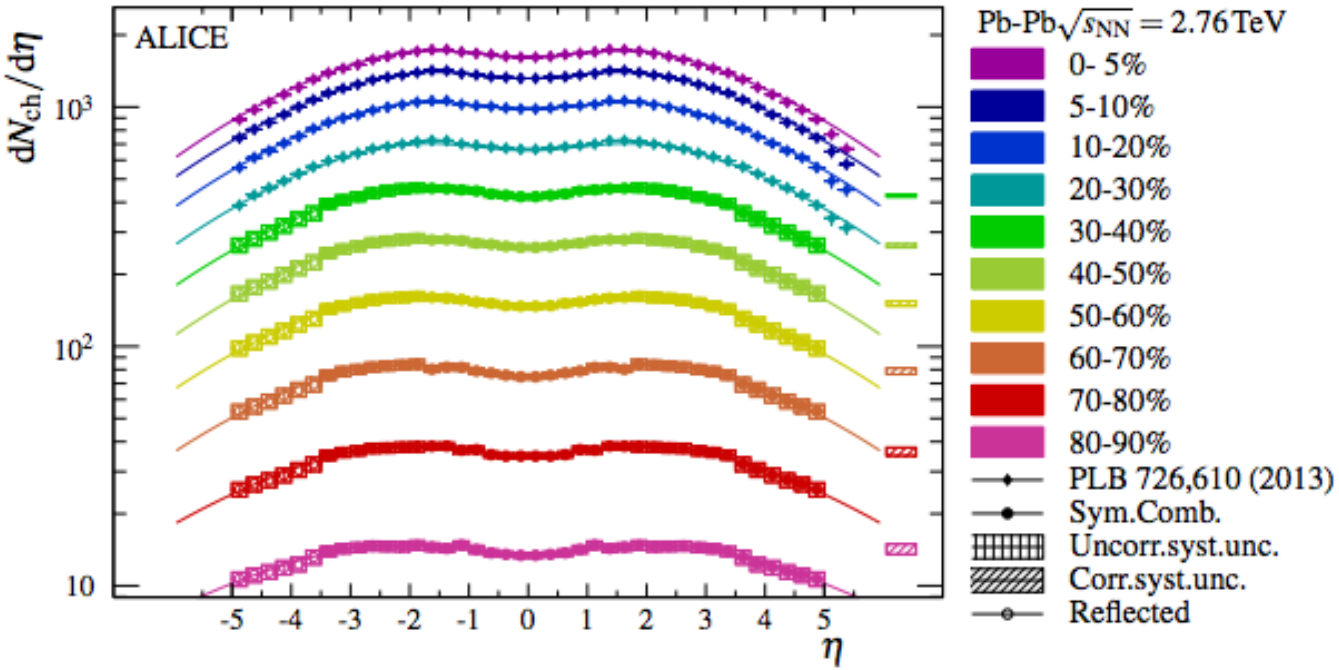


Broad rapidity coverage in ALICE (here Pb-Pb)
http://arxiv.org/pdf/1509.07299v1.pdf

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

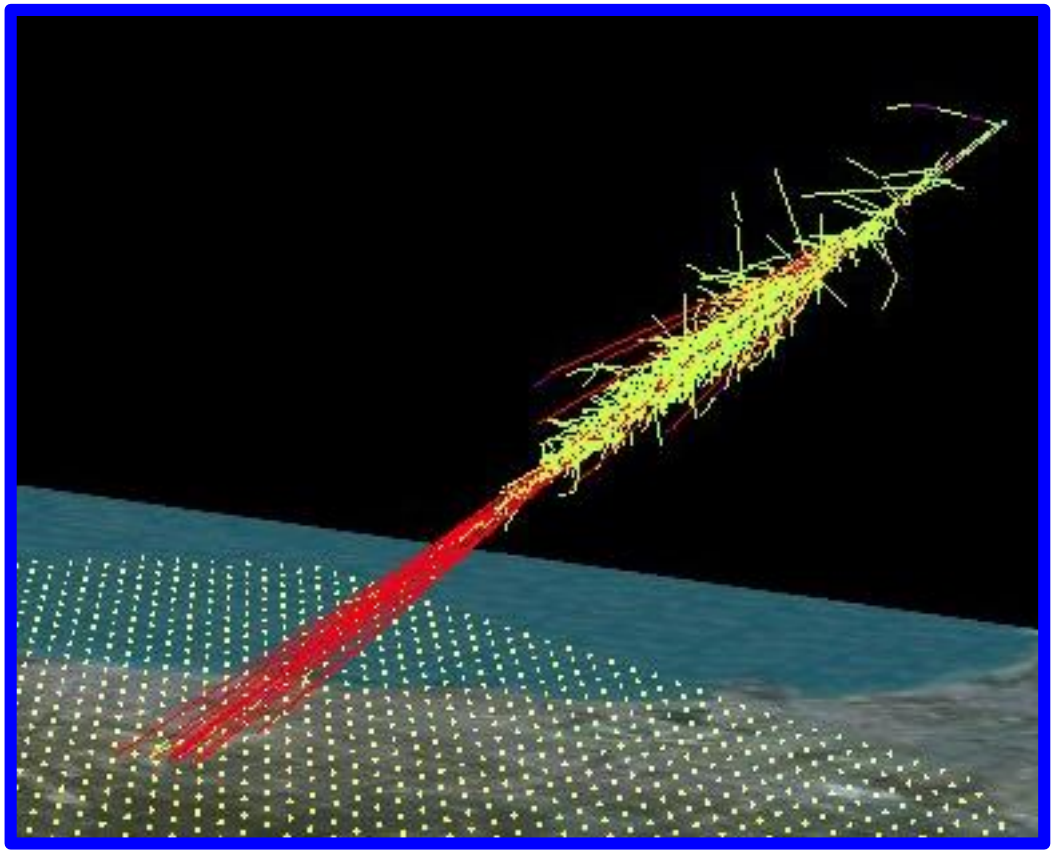
Centrality evolution of the charged-particle pseudorapidity density in Pb-Pb ALICE Collaboration



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

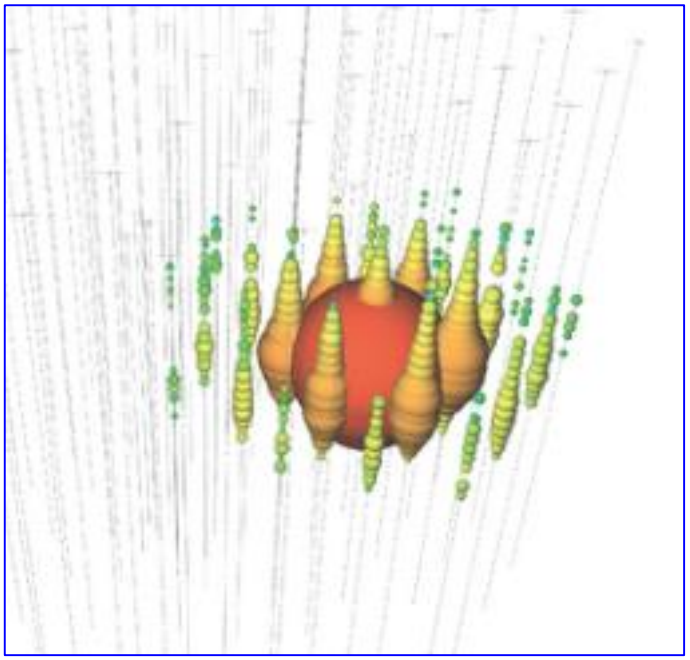
COSMIC RAY SHOWERs

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

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

MUONS!

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

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

37 years ago !

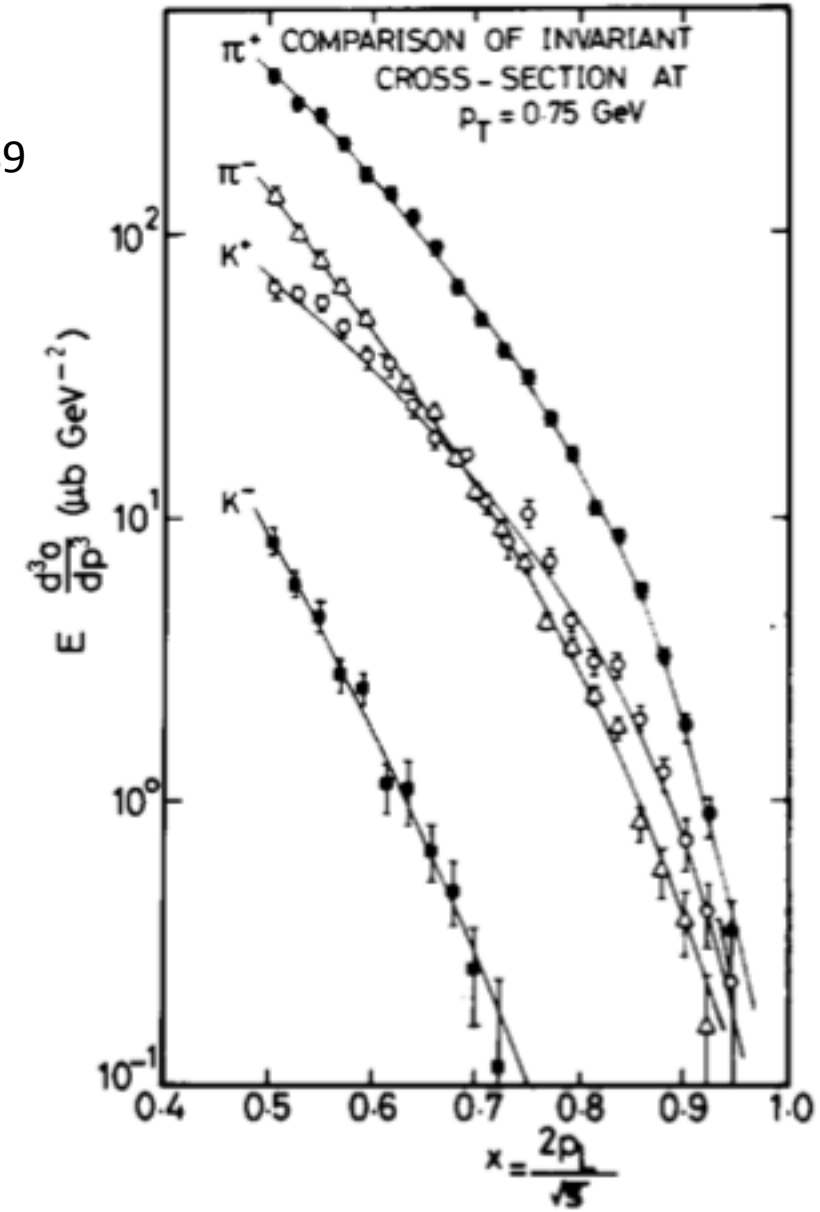


Fig. 2. Invariant cross sections for p + p → meson + X, for $p_T = 0.75$ GeV, a function of $x = 2p_L/\sqrt{s}$. The curves are empirical fits of the form $A \exp\{K(1-x)^C\}$ for $\pi^\pm$, K^+ described in the text. The curve for K^- is hand-drawn. The behaviour at other p_T values is similar.

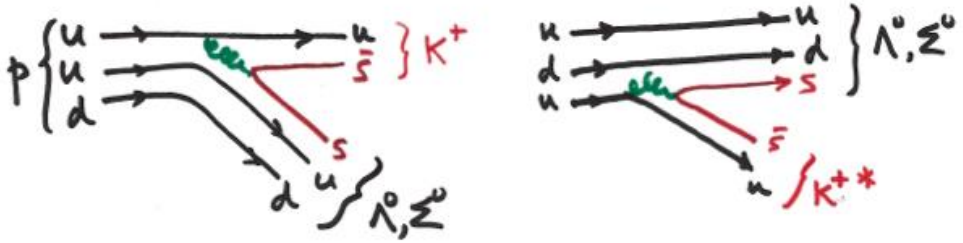
Challenge to theorists

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?). $\Sigma^0 \dashrightarrow \Lambda^0 + \gamma$ (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 (theory?) : Analyticity, unitarity and crossing symmetry + continuous complex angular momentum.

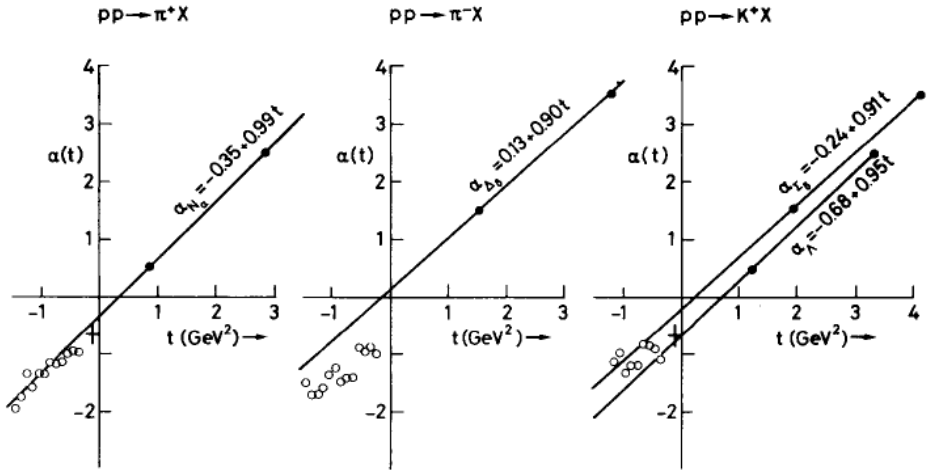


Fig. 9. Effective trajectories $\alpha(t)$ obtained from a one-term triple-Regge fit, see text.

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

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

There are relationships, 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

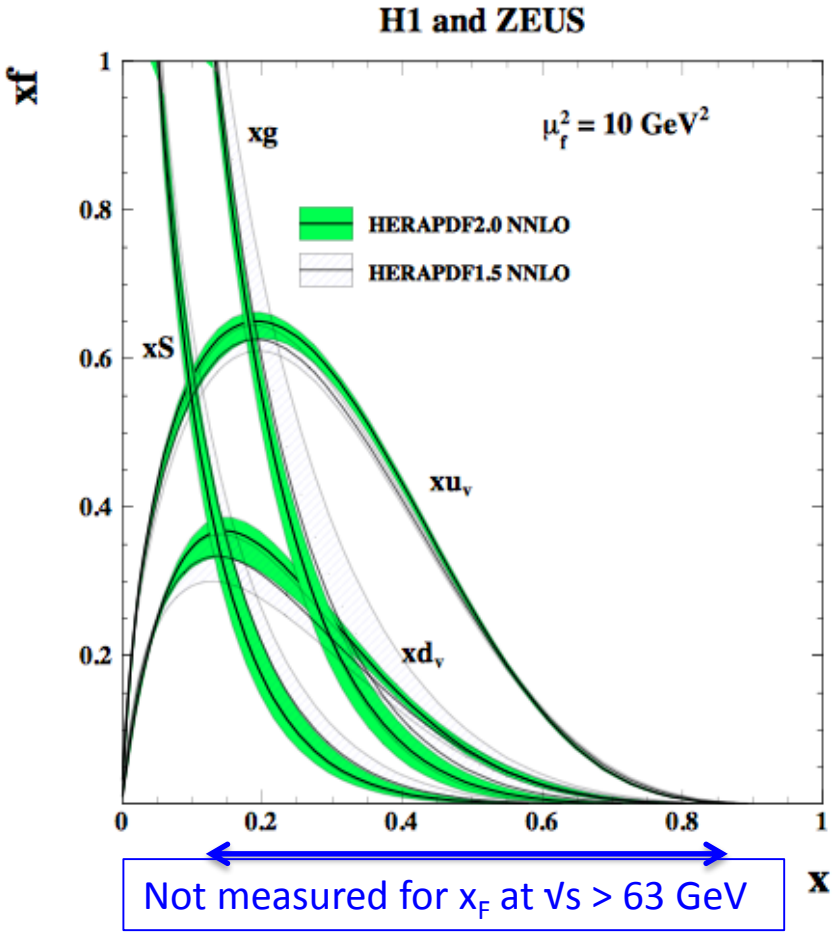
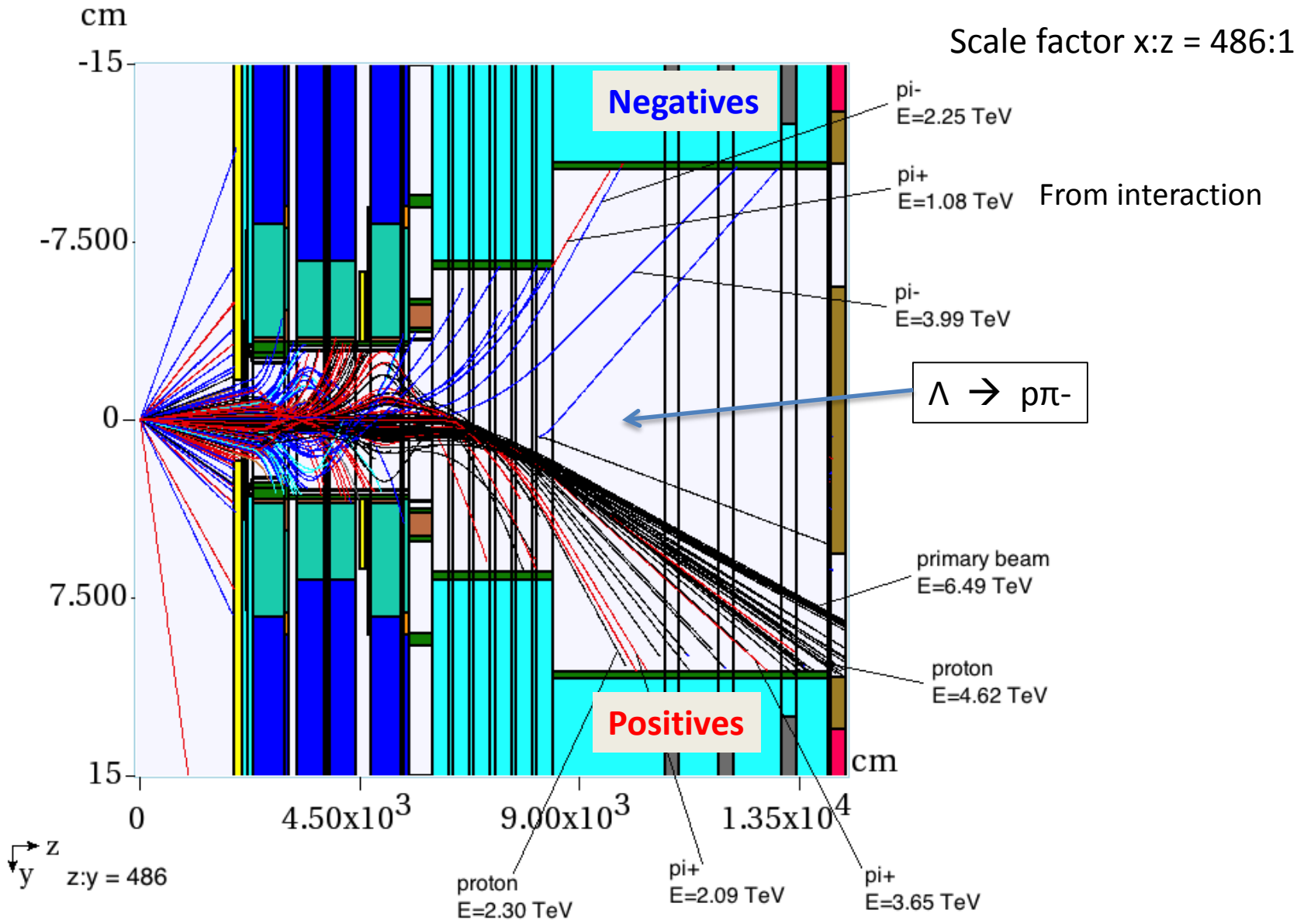


Figure 8: The parton distribution functions of HERAPDF2.0 NNLO, xu_v, xd_v, $xS = 2x(\bar{U} + \bar{D})$, xg, at $\mu_f^2 = 10\,\mathrm{GeV}^2$ compared to HERAPDF1.5 NNLO on log (top) and linear (bottom) scales.

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



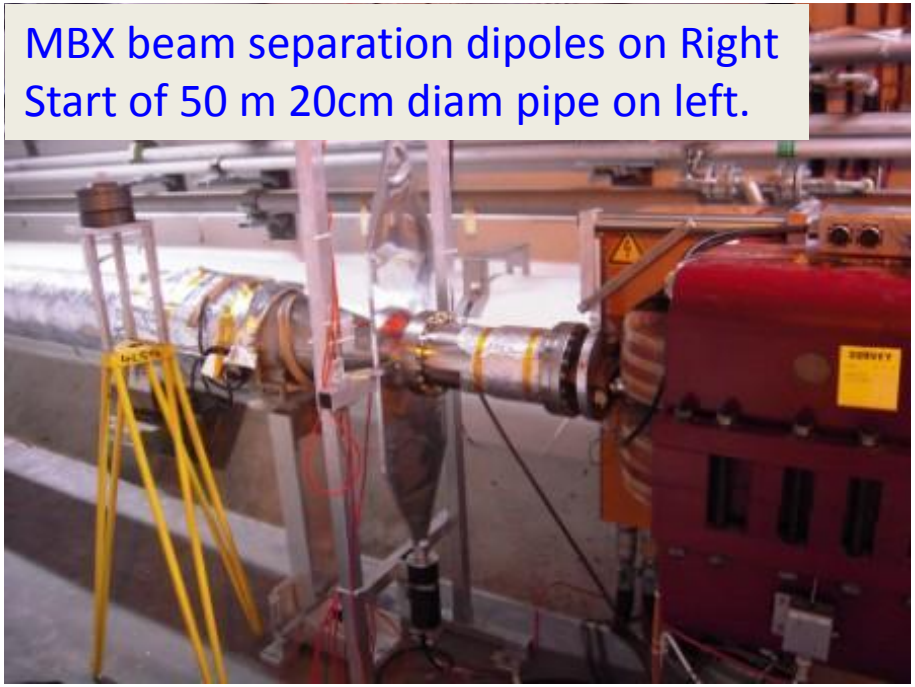
Scale factor x:z = 486:1

From interaction

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

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

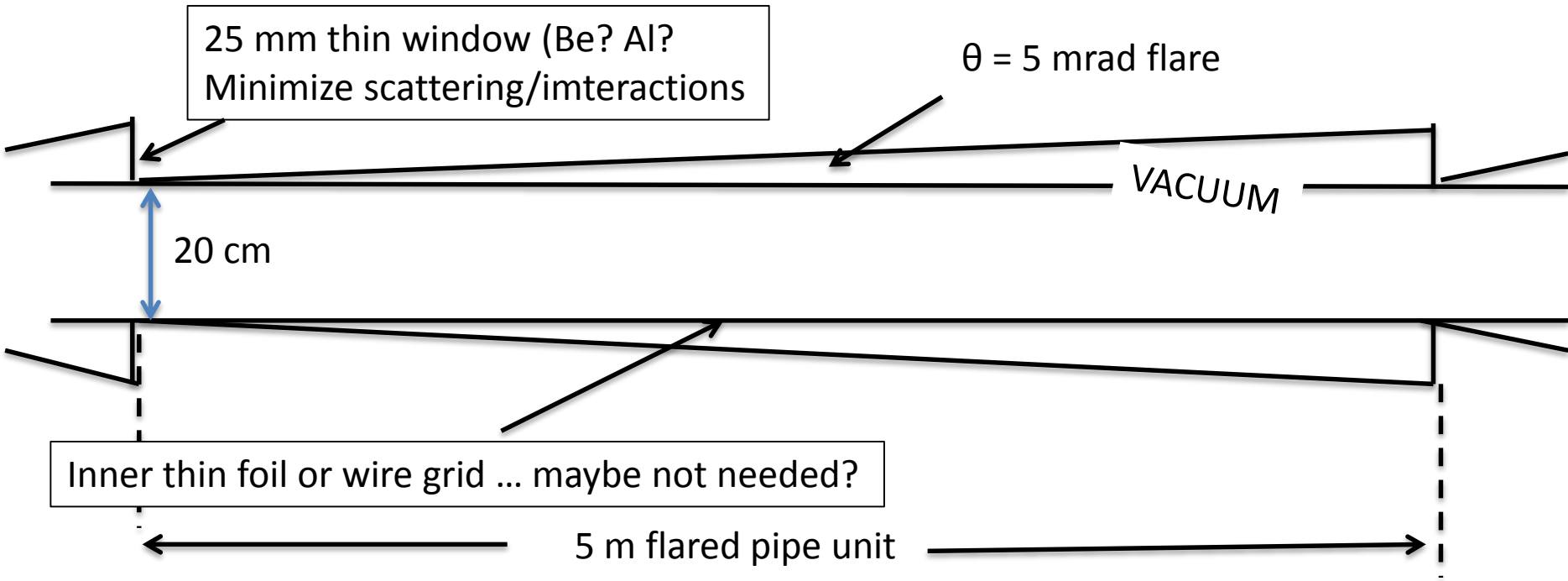
SAS: Convert this* real estate into a Sophisticated (?) multi-particle spectrometer.
* Points 2 (ALICE) AND/OR 8 (LHCb) more appropriate (Low PU, physics focus, Heavy Ions)

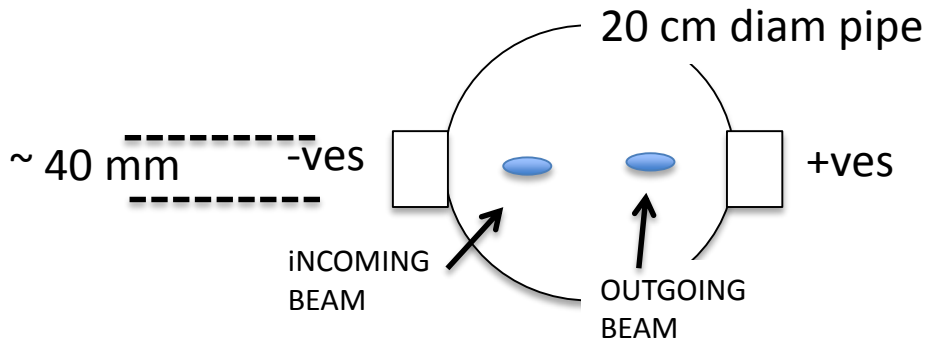
LHCb system “HERSCHEL”
Talk by Paula Collins Fri a.m.

Beam pipe design (first try, very schematic)

20 cm diameter pipe from 85m to 140m (from Point 5)
Eight flared units from z = 90m to 130m

Benoit Salvant talk





Beam pipe design #2 for small angle spectrometer (very schematic)

(Jerry Lamsa)

50 cm (?) diameter pipe from 85m to 130m (from Point 5)

Benoit Salvant talk

40 mm thin window (Be? Al?)
Minimize scattering/imteractions

10-15m for detectors

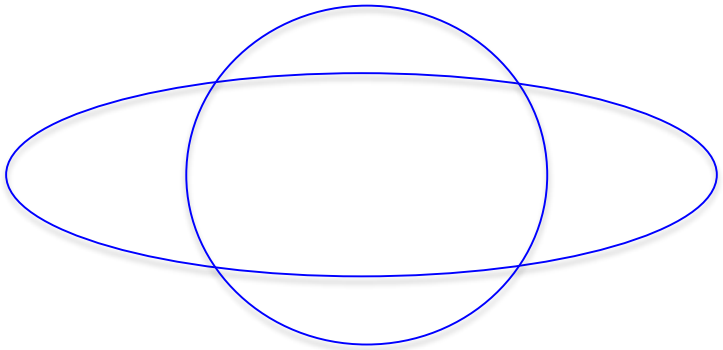
TOP VIEW

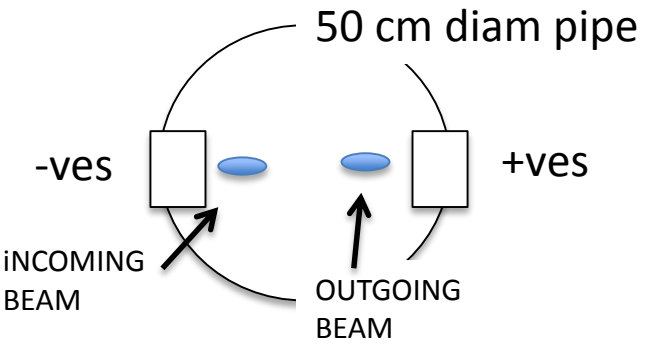
50 cm

VACUUM

Inner thin foil or wire grid

~ 40 m large pipe



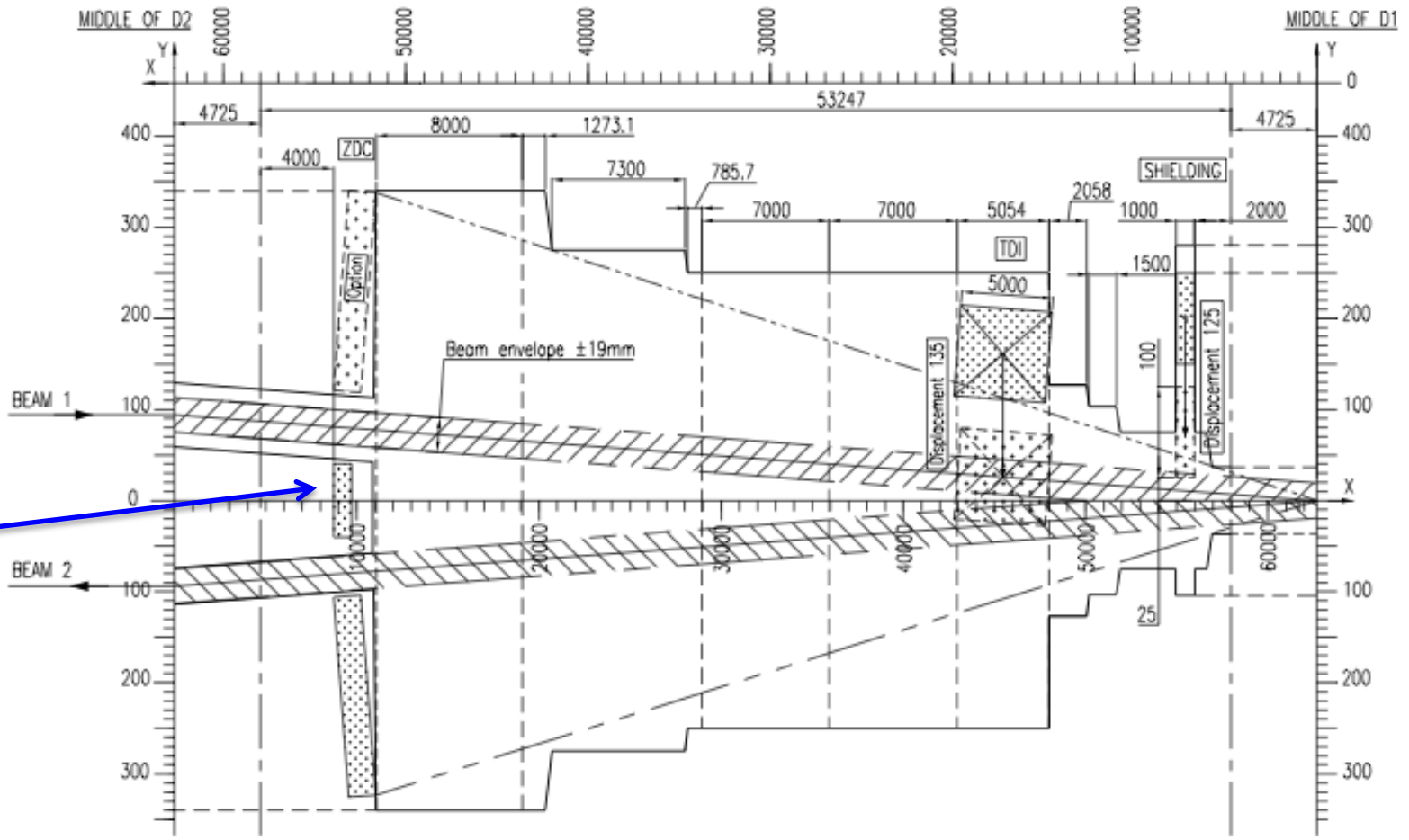


CERN / LHCC 99–5
ALICE TDR 3
5 March 1999

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

ZDC

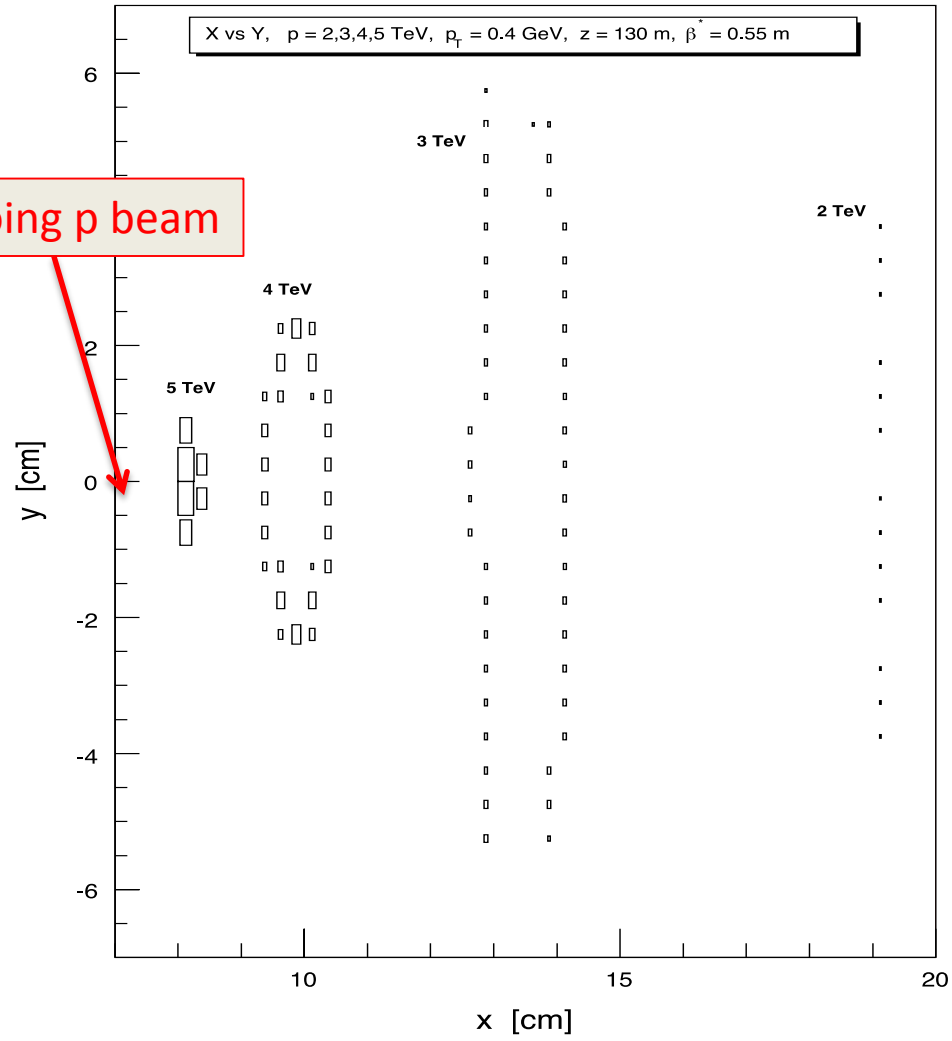
TOP VIEW



ZDC

Idea: Make space in front of calorimeter (with "thin" window) for tracking, TRDs, and behind calometer for muon measurement.
Optimise the calorimeter for few % energy measurement and good muon filtering.

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



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 pT <=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 I show 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

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

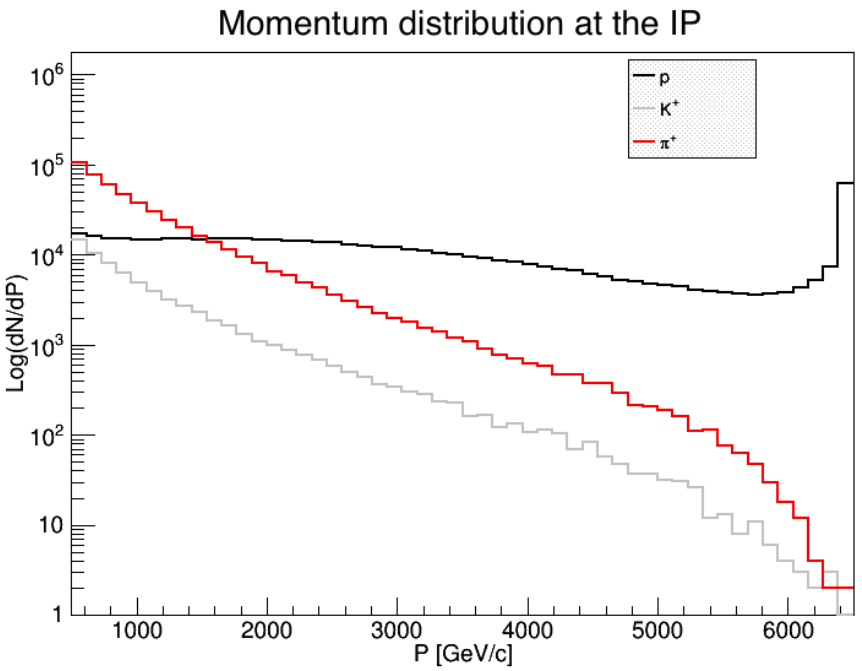
In 1 second, with 2808 bunches,
Have 30 x 10^6 bunch crossings and
30 x 10^6 x μ(= interactions/X) events.

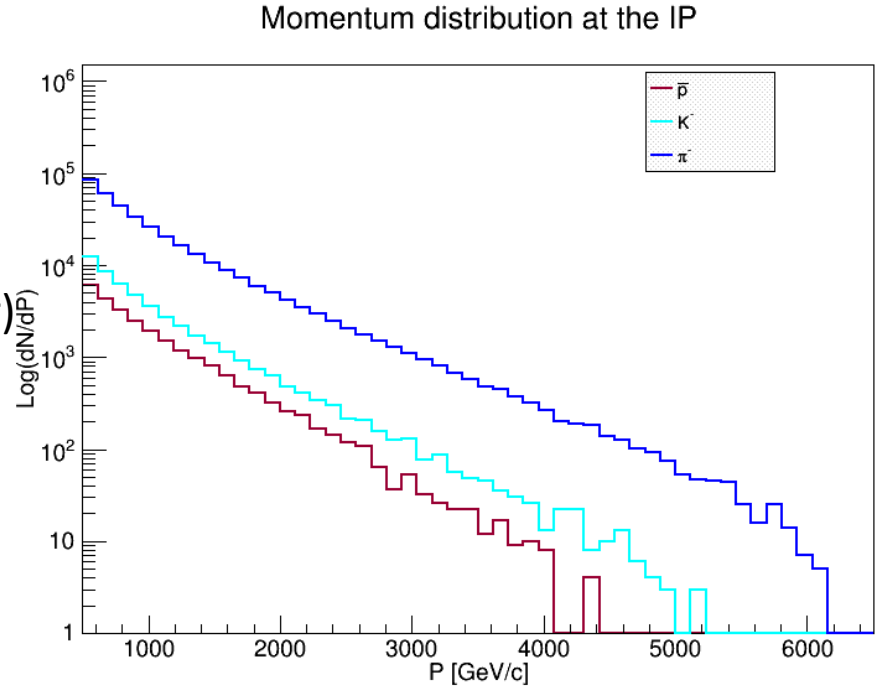
Observations:
At 0.5 TeV (~ central)
π+ = π- & K+ ≅ K- & K/π ~ 10%

p's > π+ above 1.5 TeV and flattish;
High xF peak from diffraction (IP –exch)

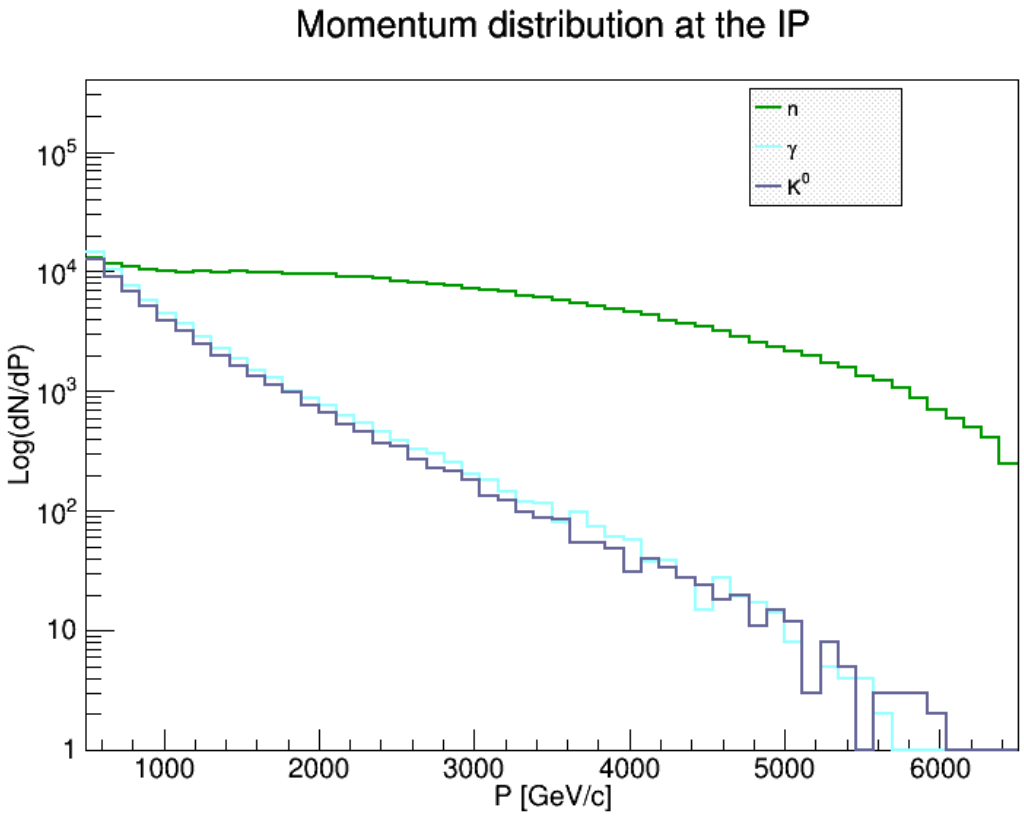
K-(s-ubar) falls more steeply than K+ (sbar-u)
π- (d-ubar) falls more steeply than π+ (u-dbar)

Antiprotons < K- but only by a factor ~ 0.5





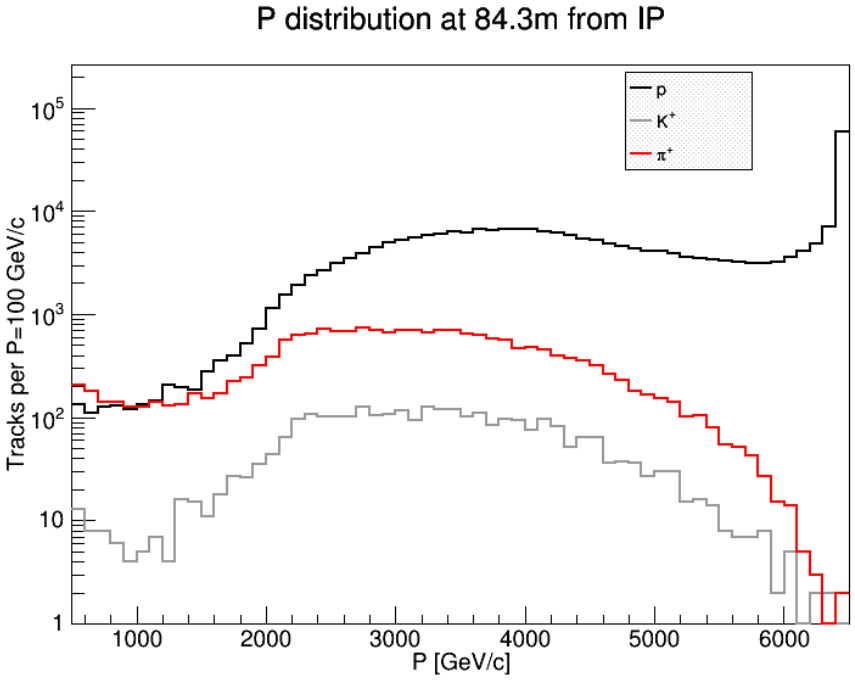
Neutral particles from collisions at 13 TeV : DPMJET predictions
Measured already in ZDC. Very different from charged particle spectra

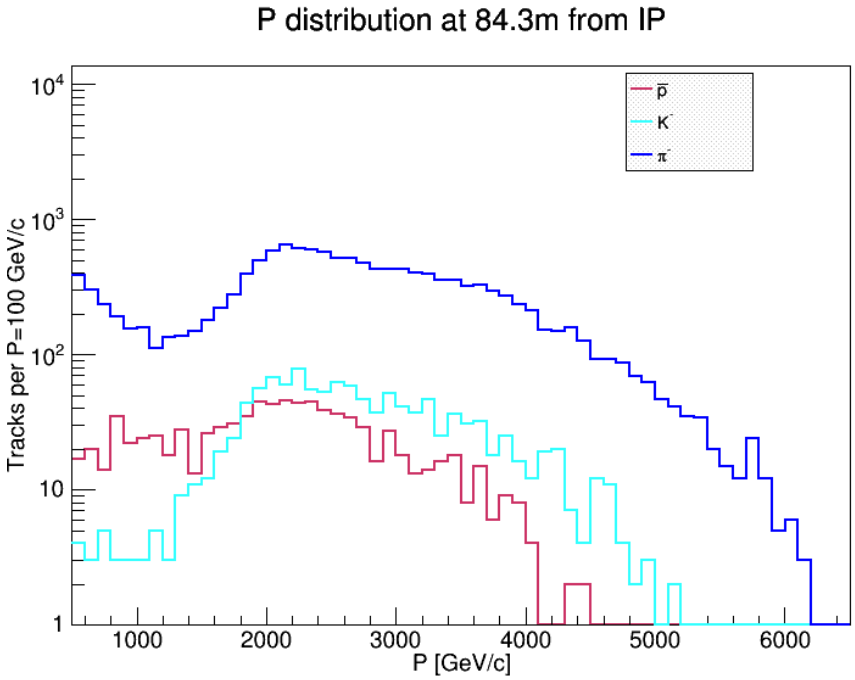


SAS@LHC would have calorimeter with EM & HADronic components.
It could be an “upgrade” to ZDC with e.g. high granularity

→ Calorimeter talks this pm on CALICE (Eva Sicking) and CMS-HGCAL (Slawek Tkaczyk)
Important for measuring E of charged hadrons too!

Momentum distribution of charged hadrons entering the 20 cm pipe at 84.3m
P(beam) = 6.5 TeV (pp). MARS simulation with 10^6 collisions





Talk by Ottavio Fornieri

SAS as a Multi-particle Spectrometer

Or FMS = Forward Multiparticle Spectrometer

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

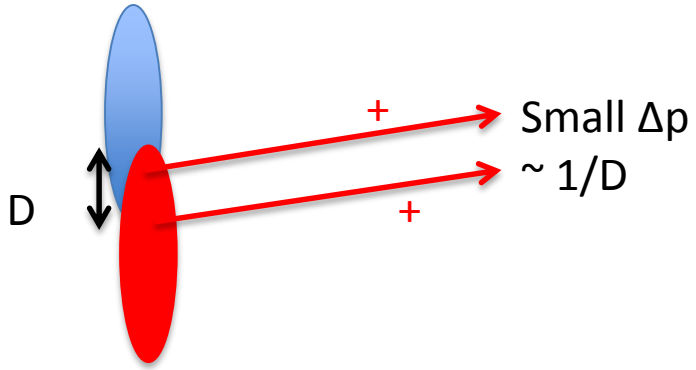
Acceptances need to be calculated … may be small or even zero for some particles
But potentially:

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

Very forward charm and beauty also "measured" with single leading e and μ
Both leptons can be identified (how well? Background from fakes?)
Leptons from π, K decay will be known, and their decay lengths are very long!

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.



Muon Measurement behind calorimeter

(and punch-through monitoring)

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%

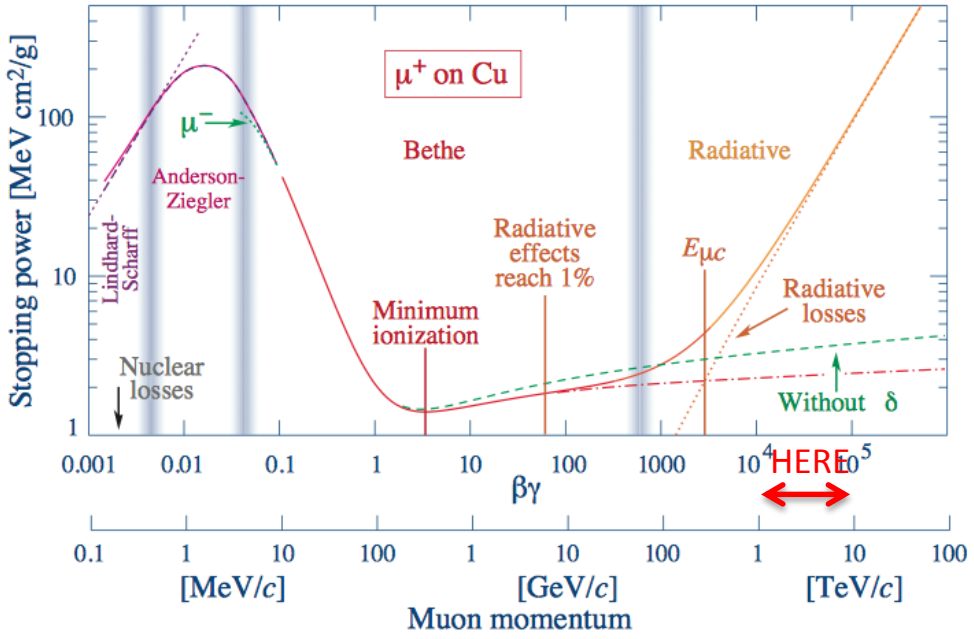
Background from π, K etc decays. γcτ(π) at 2.8 TeV = 150 km, . γcτ(K^+) = 70 km

Background from upstream interactions in pipes etc.

γ = E/m measurement from TRD (having identified muon from penetration through Calo)

Energy loss in calorimeter also fn(E)

Muon session this afternoon
Parallel 2



Calorimeters

Needed for energy measurement
Complements tracks $\Delta p/p$, and $\Delta E/E \sim 5\%$ probably achievable.

EM and HADronic sections … can be very deep – good muon filter
Can profit from major developments in high granularity calorimeters
But our modules much smaller (protoype test module size):

HGCAL for CMS upgrade : Slawek Tkaczyk talk
CALICE (linear colliders) : Eva Sicking talk

Transition Radiation Detectors - TRD

Probably only technique for distinguishing π / K / p at multi-TeV energies
All $\beta = 1.0000 - \varepsilon$ so Cherenkov counters no good

Interesting challenge : merits a full afternoon workshop today
Conveners : Christoph Rembser and Anatoli Romaniouk

Identification of π/K/p : Main technology challenge! (Chystals 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

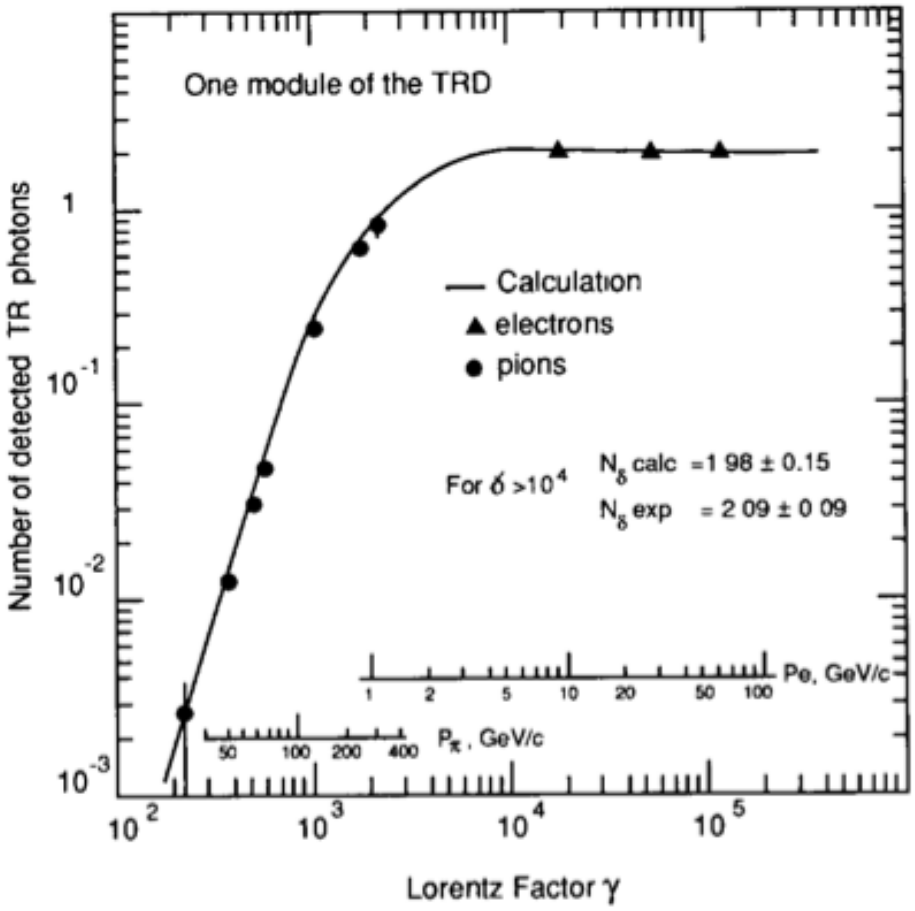
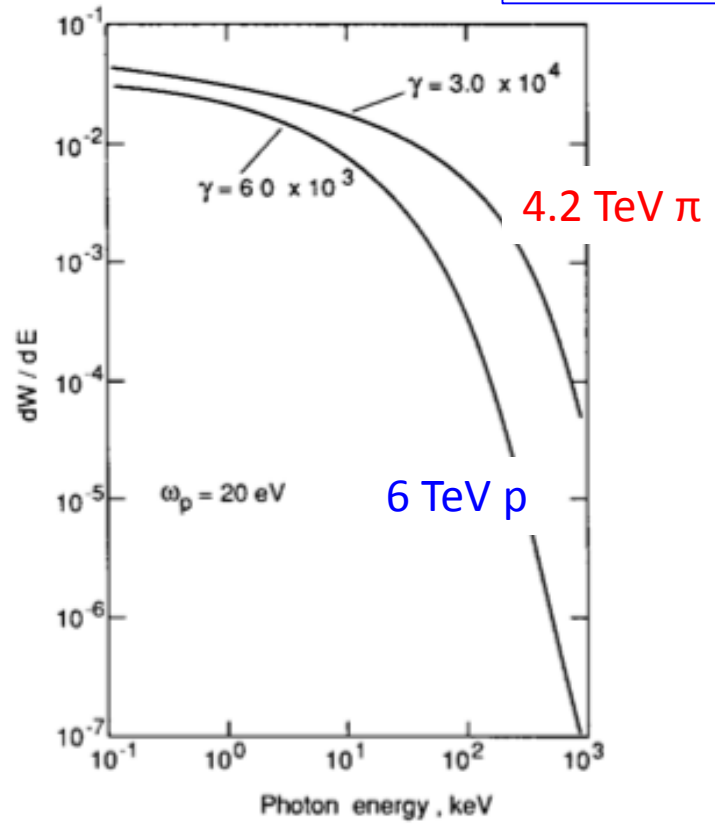


Fig. 12. Comparison of the detected number of TR photons with MC calculation for various γ-values (TR radiator: CH_2 foils).



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

Session this p.m. on TDRs
Christoph Rembser & Anatoli Romaniouk

Bent crystal channeling

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)

Walter Scandale and Gianluca Cavoto (UA9 collaboration … tests in SPS, LHC)
Talk tomorrow morning (Cavoto)

?? Optional extra, perhaps a Stage 2 ??
Protons probably > 99% at x_F = 0.9 so TRD may not be justified ??
Although rarest *may* be most interesting!

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 1 TRDs

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

Rest. 2

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** *2*
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

Thursday afternoon parallel session 2 (Bldg 60 is near auditorium)

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)

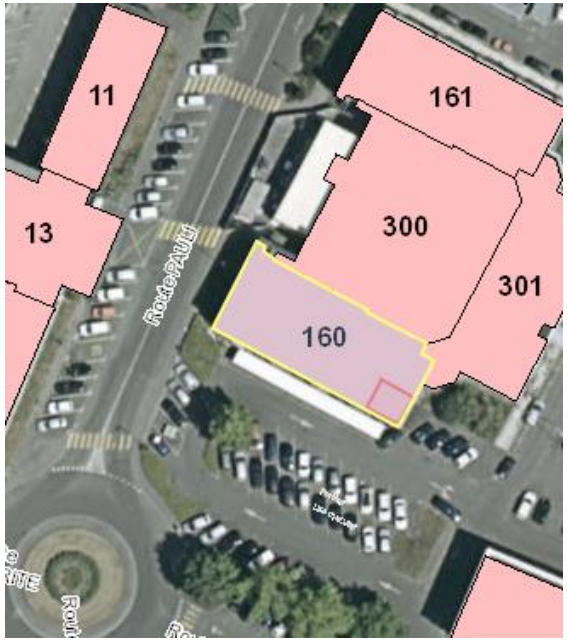
15:00 **CT-PPS Tracking for SAS@LHC TBC** *20'*
Speaker: Nicolo Cartiglia (Universita e INFN Torino (IT))

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

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

Friday Plenary (Bat. 160)

Main Gate



09:00 - 13:30 **Plenary**

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

Location: 160-R-009

10:00 **Channeling for high-xF** *30'*
Speaker: Gianluca Cavoto (Universita e INFN, Roma I (IT))

10:30 **Transition radiation summary report & plans** *30'*
Speaker: Christoph Rembser (CERN)

11:00 **Calorimeter summary report** *20'*

11:30 **Coffee** *15'*

11:45 **LHCb very forward detectors** *30'*
Speaker: Paula Collins (CERN)

12:15 **SAS at ALICE** *30'*
Speaker: Risto Orava (Helsinki Institute of Physics (FI))

12:45 **Acceptance, rates, running conditions** *20'*
Speaker: ALL

14:00 - 18:00 **Plenary session**

Join

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

Location: 160-1-009

14:00 **Open discussion: Stand-alone SAS? Extensions of ALICE, LHCb, other** *45*
Speaker: ALL

14:45 **Plans (to TDR/LOI , Proposal?, time scale)** *45'*
Speaker: Michael Albrow (Fermi National Accelerator Lab. (US))

“Goal” (or my hope) for this meeting

Is there some “show stopper” that makes it not feasible? If not:

Is the physics case strong enough (or can it be) to motivate developing it?

What are the main challenges and are they tractable?

Should a team (collaboration?) be formed to do it as an “independent” experiment?

Or should it be pursued within the ALICE and/or LHCb collaborations as an extension of their coverage and of their physics program?

Issues of effort, time-scale, cost, etc depend strongly on above paths taken.