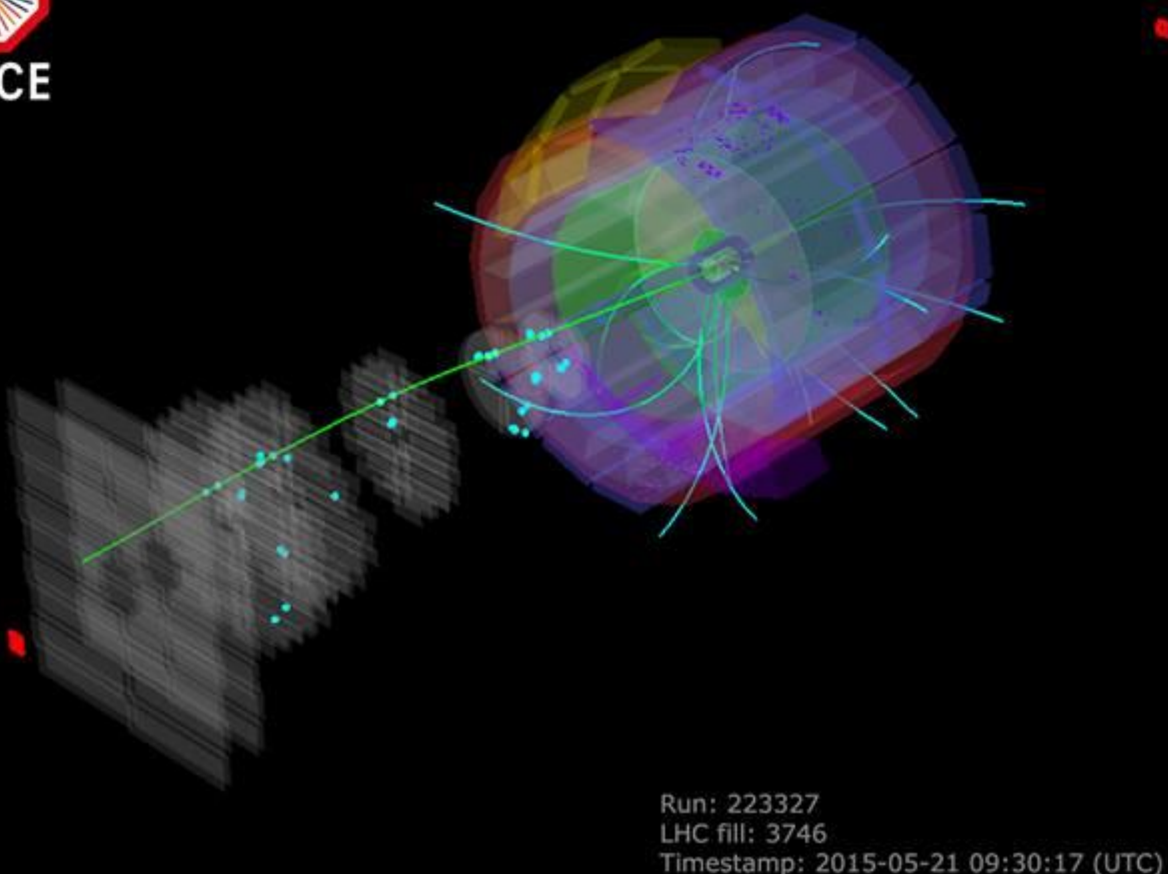
Diffractive physics in ALICE at the LHC

ALICE



LISHEP 2015
Manaus, Amazonas, Brasil, August. 2-9, 2015

Gerardo Herrera Corral
CINVESTAV - México
on behalf of ALICE Collab.

ALICE talks

- Cosmic Ray Physics with ALICE
  by A. Fernandez today 17:20

- Heavy ions physics at ALICE CMS and ATLAS
  by B. Wyslouch tomorrow 4-August

- Photon and neutral pion production in pp and PbPb collisions at the LHC energies in ALICE.
  by Podist Kurashvili 5-August

- Transverse polarization measurement of Lambda particles with ALICE at the LHC
- By Liliet Calero 8-August

$$Pb = 82\,p + 126\,n$$

2.76 TeV/nucleon

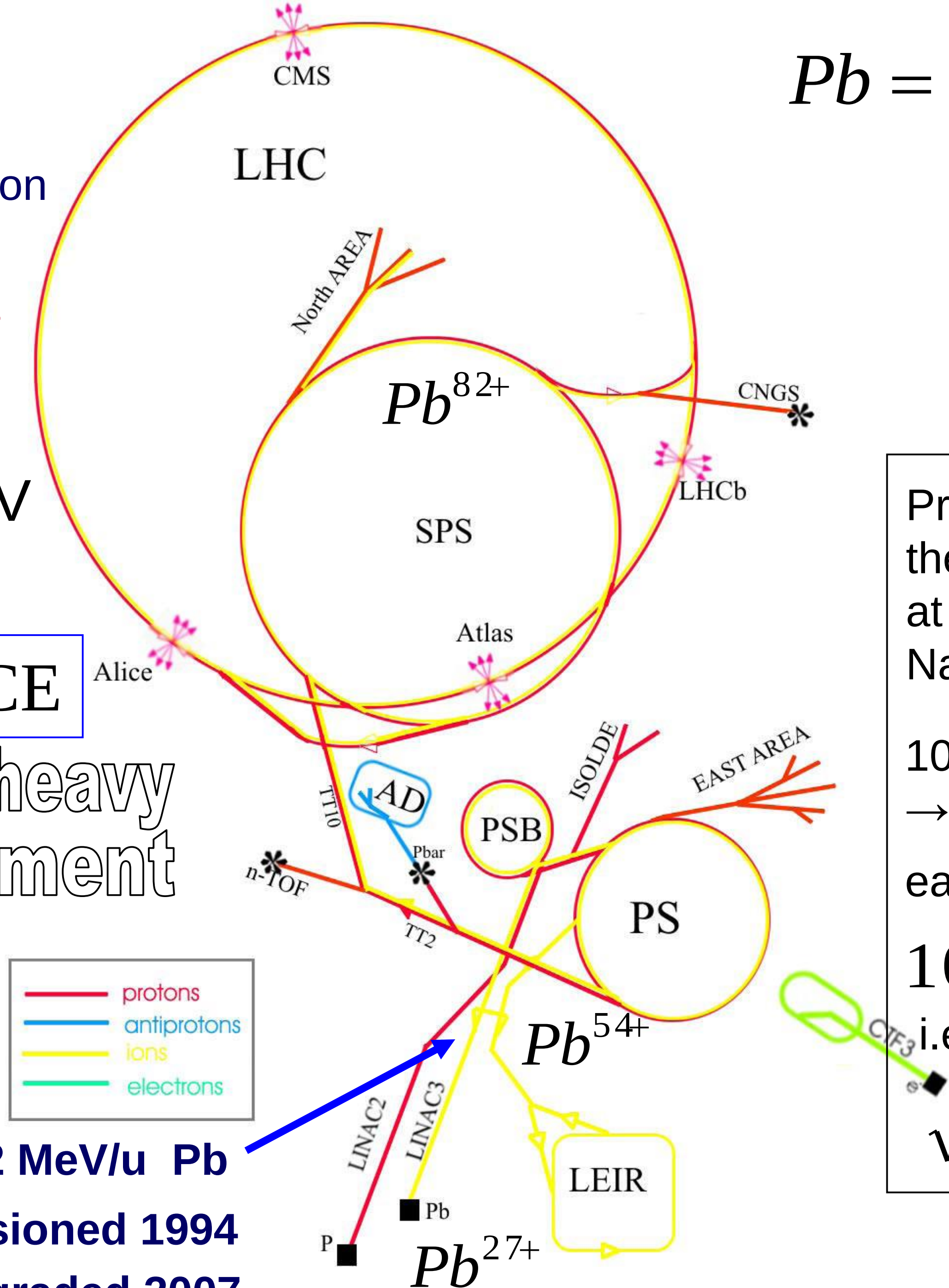
LARGE amounts of energy involved

$\sqrt{s} = 1154$ TeV

Pb – Pb collisions

ALICE

dedicated heavy ion experiment



4.2 MeV/u Pb

commissioned 1994

upgraded 2007

fully stripped Pb ions

$$Pb^{82+}$$

Previous project in the field RHIC at Brookhaven National Laboratory

100 GeV/nucleon
→ Gold nucleus

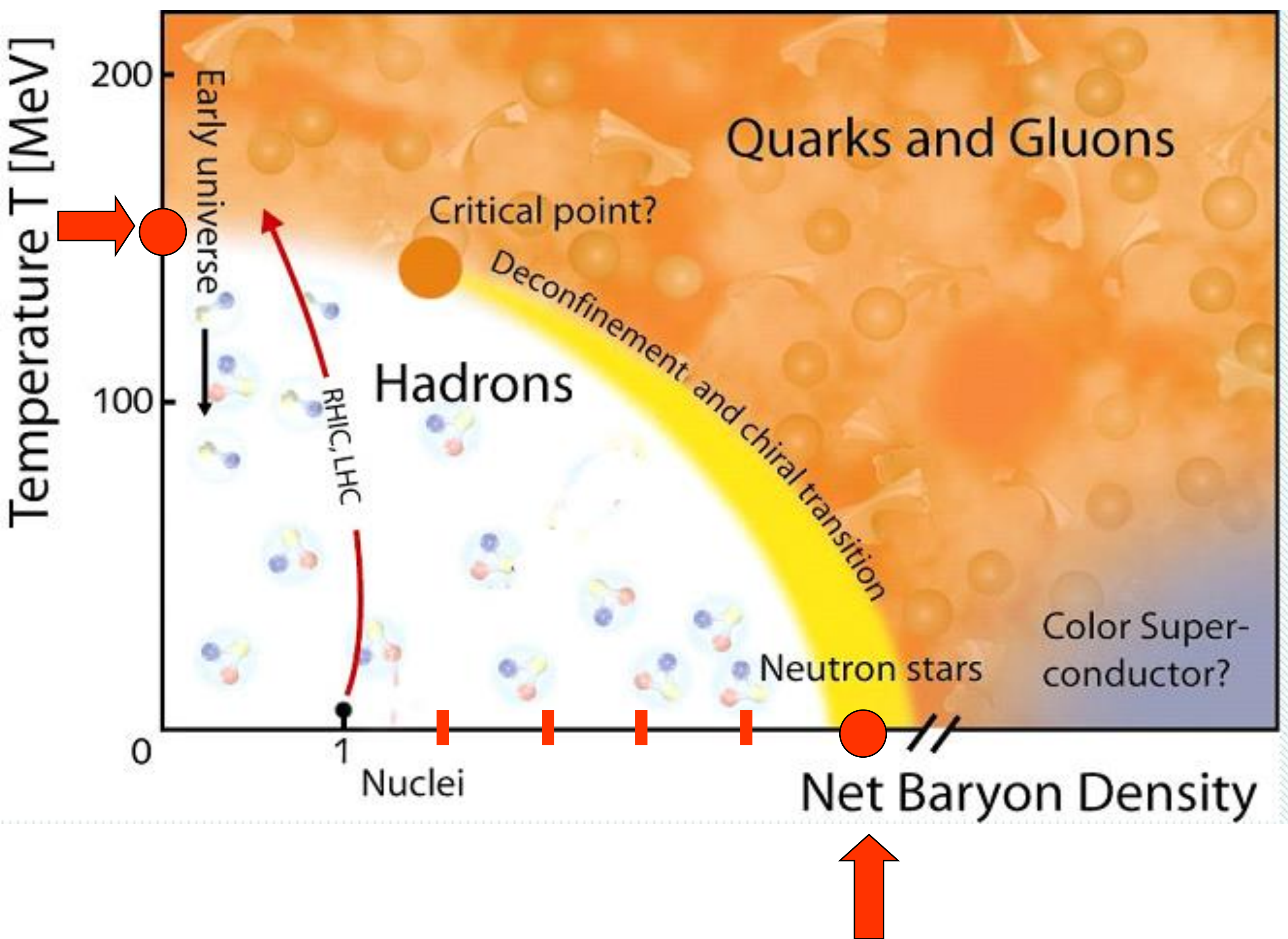
each nucleus

100×197 GeV

i.e. 19.7 TeV

$\sqrt{s} = 39.4$ TeV

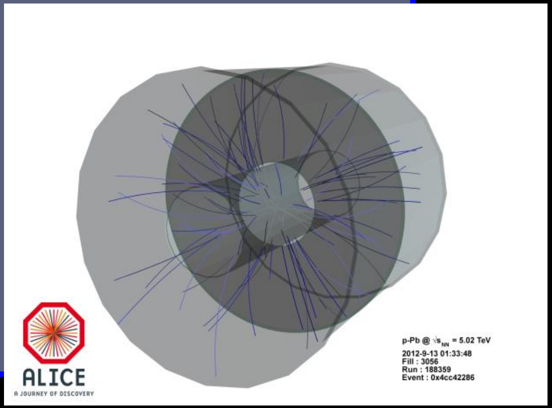
Phase Diagram of QCD Matter



LHC heavy ion runs

- **Two heavy-ion runs at the LHC so far:**
  - 2010 – commissioning and first data taking
  - 2011 – above nominal instant luminosity
- **p–Pb next year – 2013**
  - plan for ~ 30 nb^{-1}

  pilot run September 12th successful !!!
- **Long Shutdown in 2013-2014**



year	system	Energy $\sqrt{s_{NN}}$ (TeV)	integrated luminosity
2010	**Pb – Pb**	**2.76**	**~ 10 μb^{-1}**
2011	**Pb – Pb**	**2.76**	**~ 0.1 nb^{-1}**
2013	**p – Pb**	**5.02**	**~ 30 nb^{-1}**

The program of ALICE

ALICE heavy-ion program approved for ~ 1 nb^{-1}:

- **2015 Pb–Pb at $\sqrt{s_{NN}}$ = 5.1 TeV**
- **2016–17 Pb–Pb at $\sqrt{s_{NN}}$ = 5.5 TeV**

- **2018 Long Shutdown 2**
- **2019 probably Ar–Ar high-luminosity run**
- **2020 p–Pb comparison run at full energy**
- **2021 Pb–Pb run to complete initial ALICE program**
- **2022 Long Shutdown 3**

This will improve statistical significance of our main results (~ x 3)

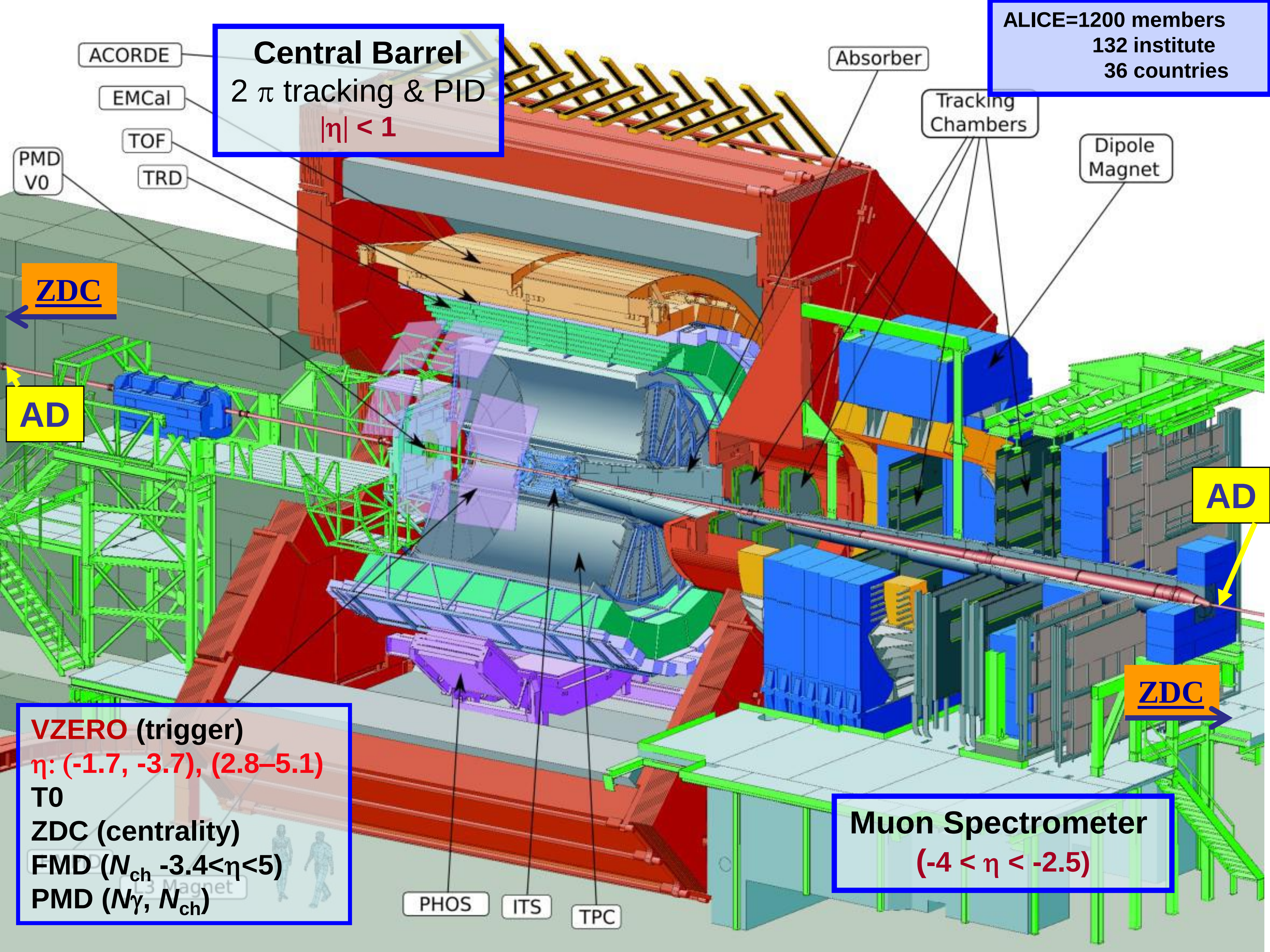
ALICE proton proton

Run 2 2015 – 2017:

- 2015 proton–proton at $\sqrt{s_{pp}} = 13$ TeV
  starting at $\sqrt{s_{pp}} = 12$ TeV -- 25 ns bunch spacing
- Possibility of low luminosity and low beam intensity
  Minimum Bias Trigger - OR
- Lab energy increases $\rightarrow$
- Better pseudorapidity coverage $\rightarrow$
- UPC cross section increase with energy ($J/\Psi, \Psi', \Upsilon$)

Run 3 2019 – 2021:

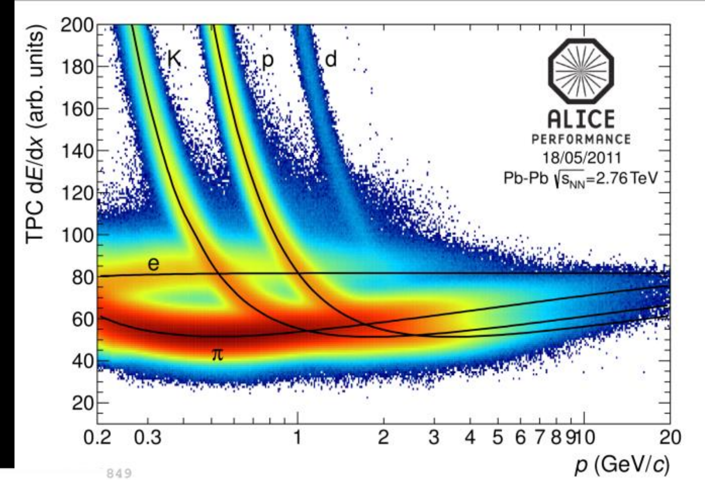
- proton–proton at $\sqrt{s_{pp}} = 14$ TeV
- Upgraded ALICE detector (Calorimetry, faster read-out, new beam pipe, different Internal Tracking System etc.)
- New Trigger Detectors


ALICE=1200 members
132 institute
36 countries
Central Barrel
2 π tracking & PID
|η| < 1
ACORDE
EMCal
TOF
TRD
PMD
V0
Absorber
Tracking Chambers
Dipole Magnet
ZDC
AD
AD
ZDC
VZERO (trigger)
η: (-1.7, -3.7), (2.8–5.1)
T0
ZDC (centrality)
FMD (N_{ch} -3.4<η<5)
PMD ($N\gamma$, N_{ch})
PHOS
ITS
TPC
Muon Spectrometer
(-4 < η < -2.5)

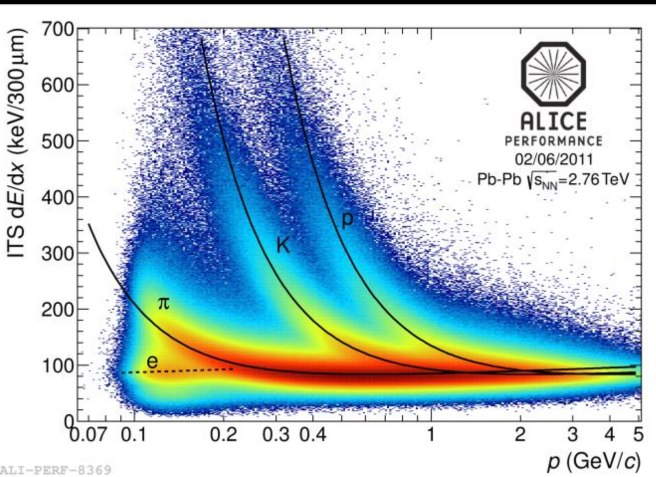
all known techniques for particle identification:

inclusive and exclusive particle production in centrally produced systems, in various channels …

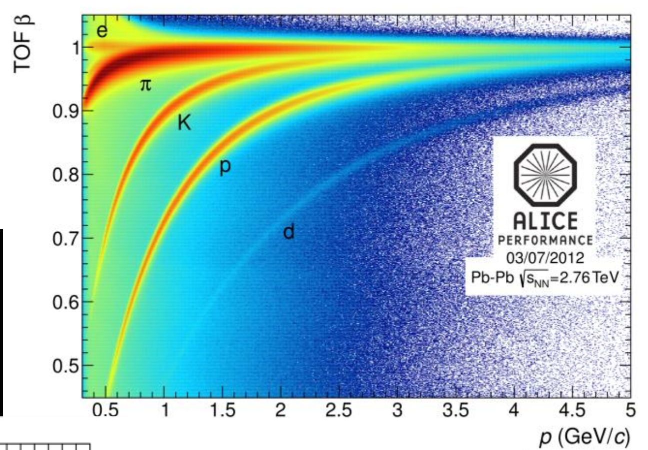
in progress



TPC

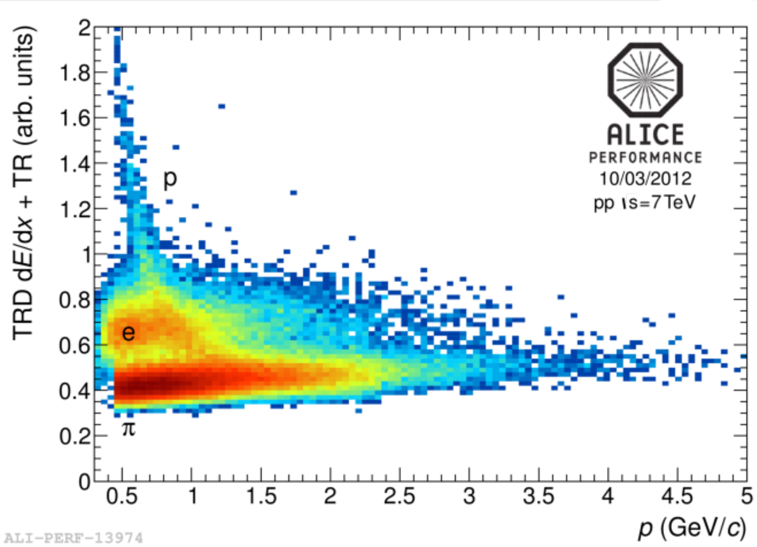


ITS

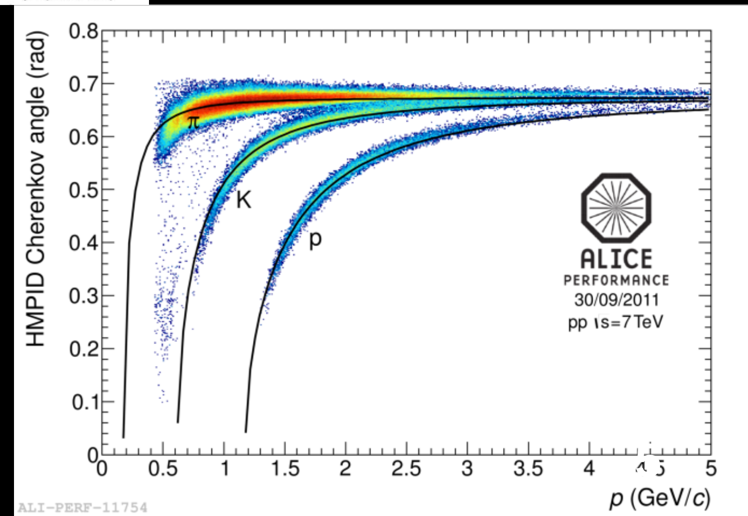


TOF

HMPID



TRD



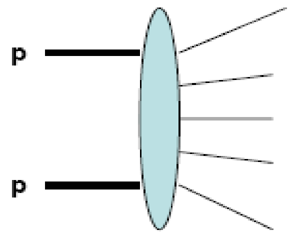
Diffractive Physics

&

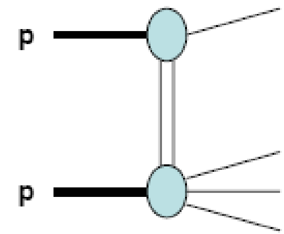
ALICE

Diffractive and Non Diffractive Interactions

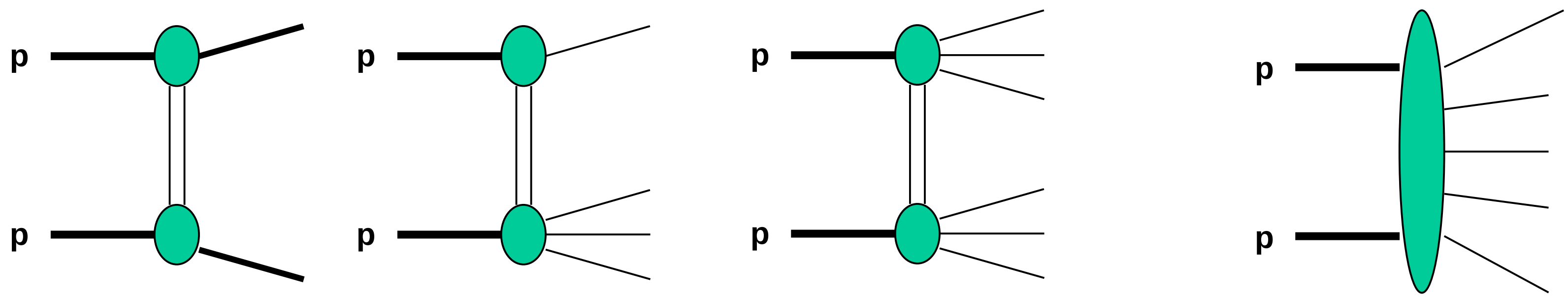
non diffractive → no gaps
color exchange



diffractive → gaps
colorless exchange



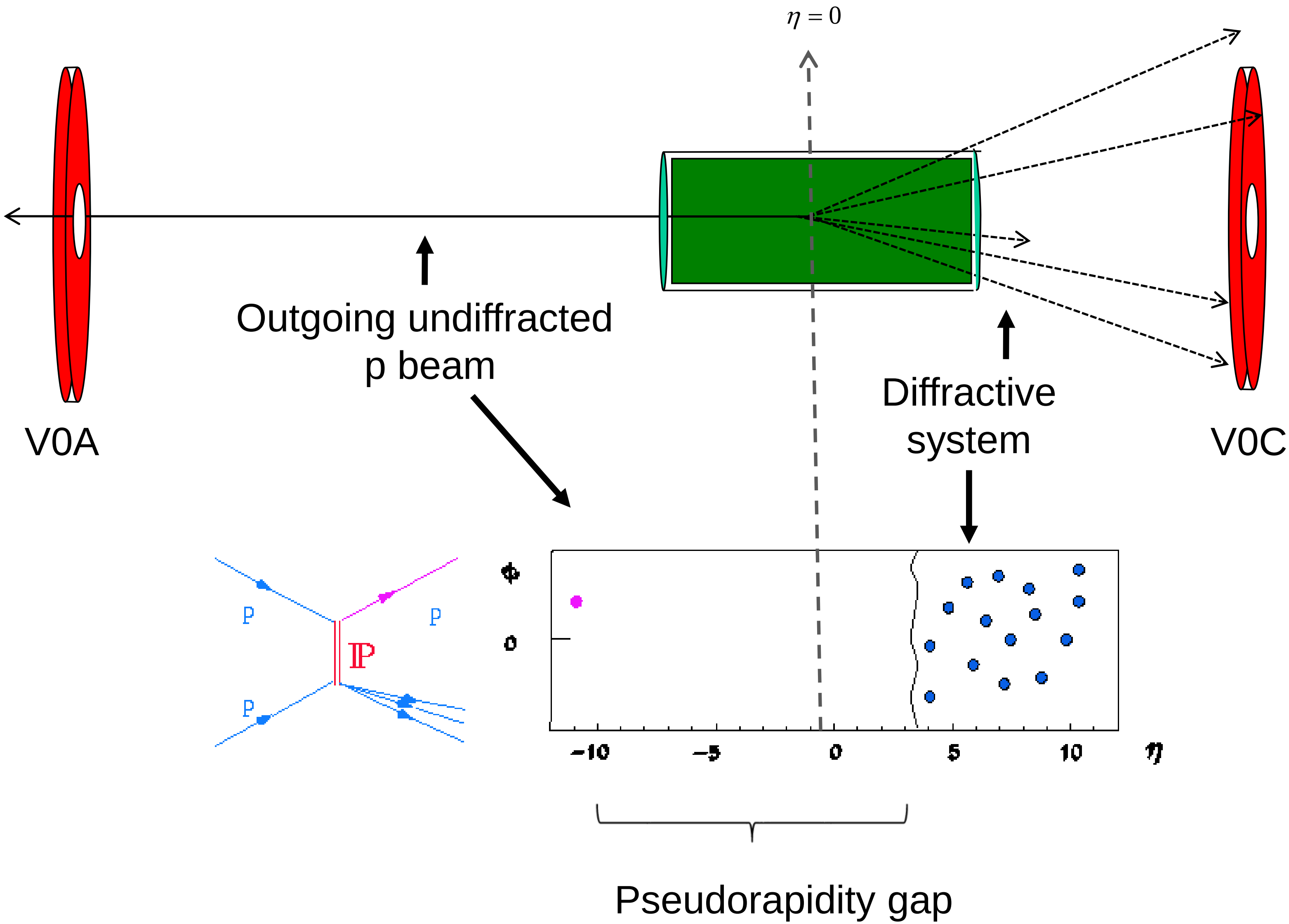
$$\sigma_{tot} = \sigma_{elastic} + \sigma_{single-diffractive} + \sigma_{double-diffractive} + \cdots + \sigma_{non-diffractive}$$



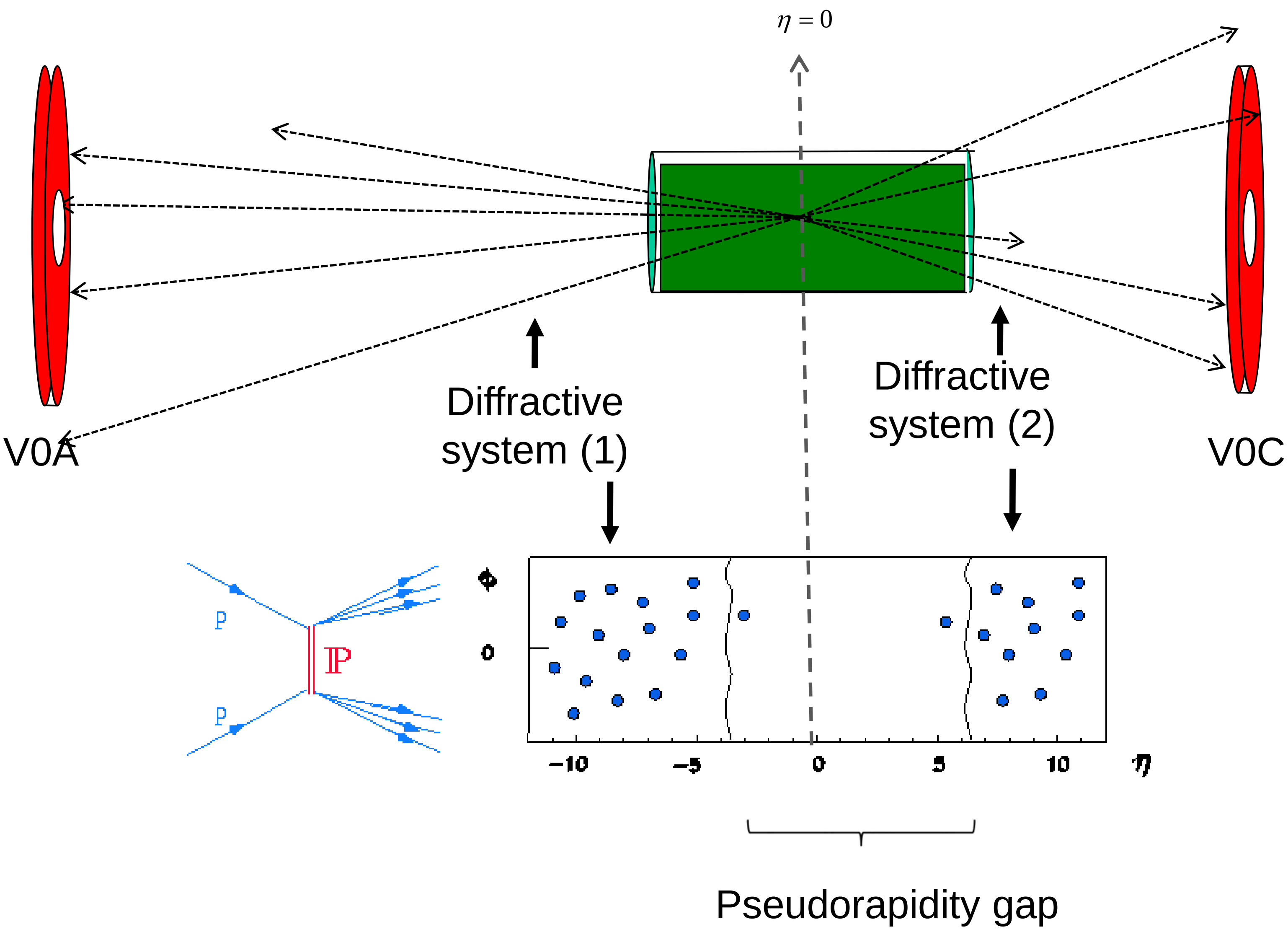
•True cross sections at LHC energies are not known
• Scaling of cross sections with energy is model dependent

PHOJET	Default fractions	PYTHIA
0.134	SD	0.187
0.063	DD	0.127

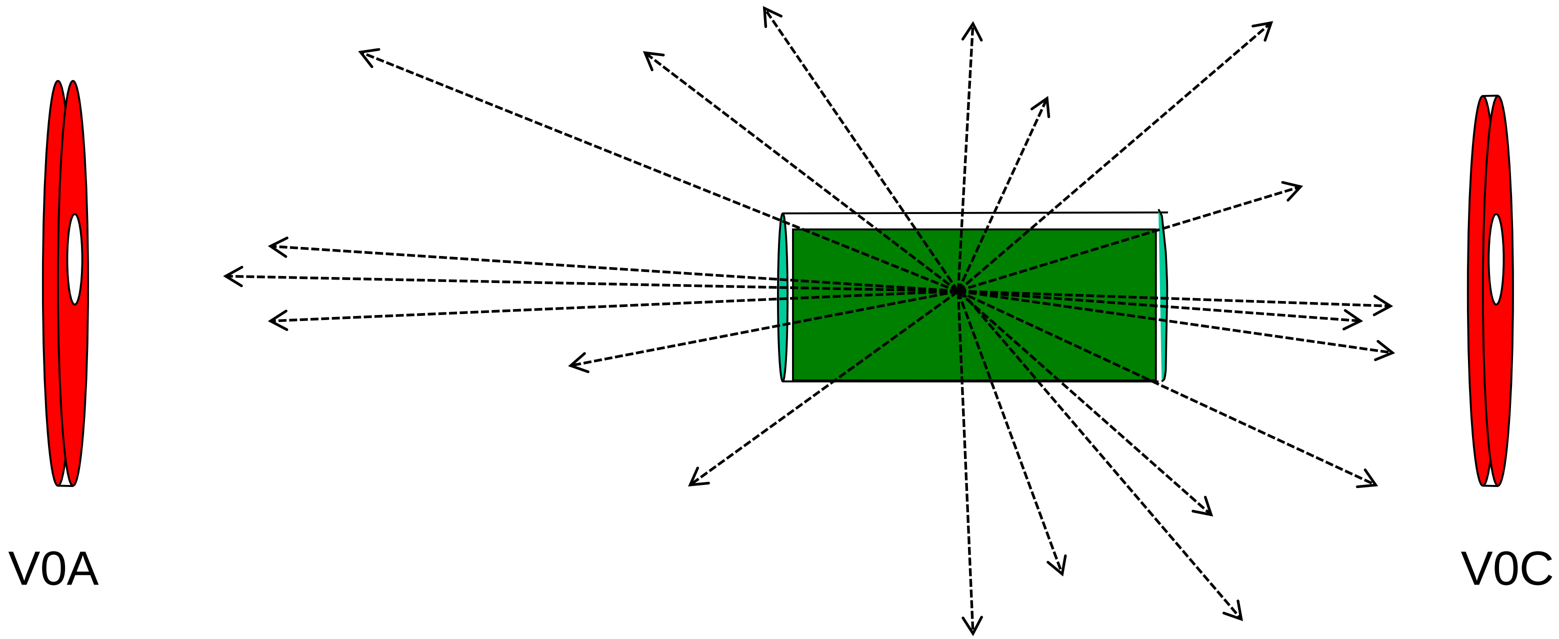
Single Diffraction (SD)

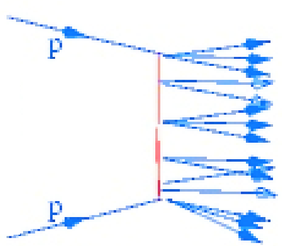


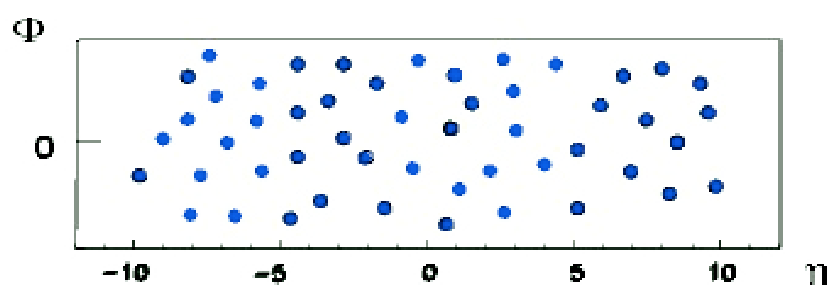
Double Diffraction (DD)



Non Diffractive (ND)



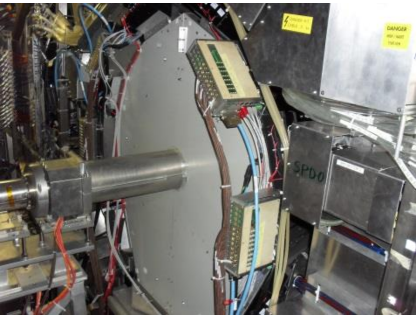




No pseudorapidity gap

Instrumentation for diffractive physics in ALICE - today

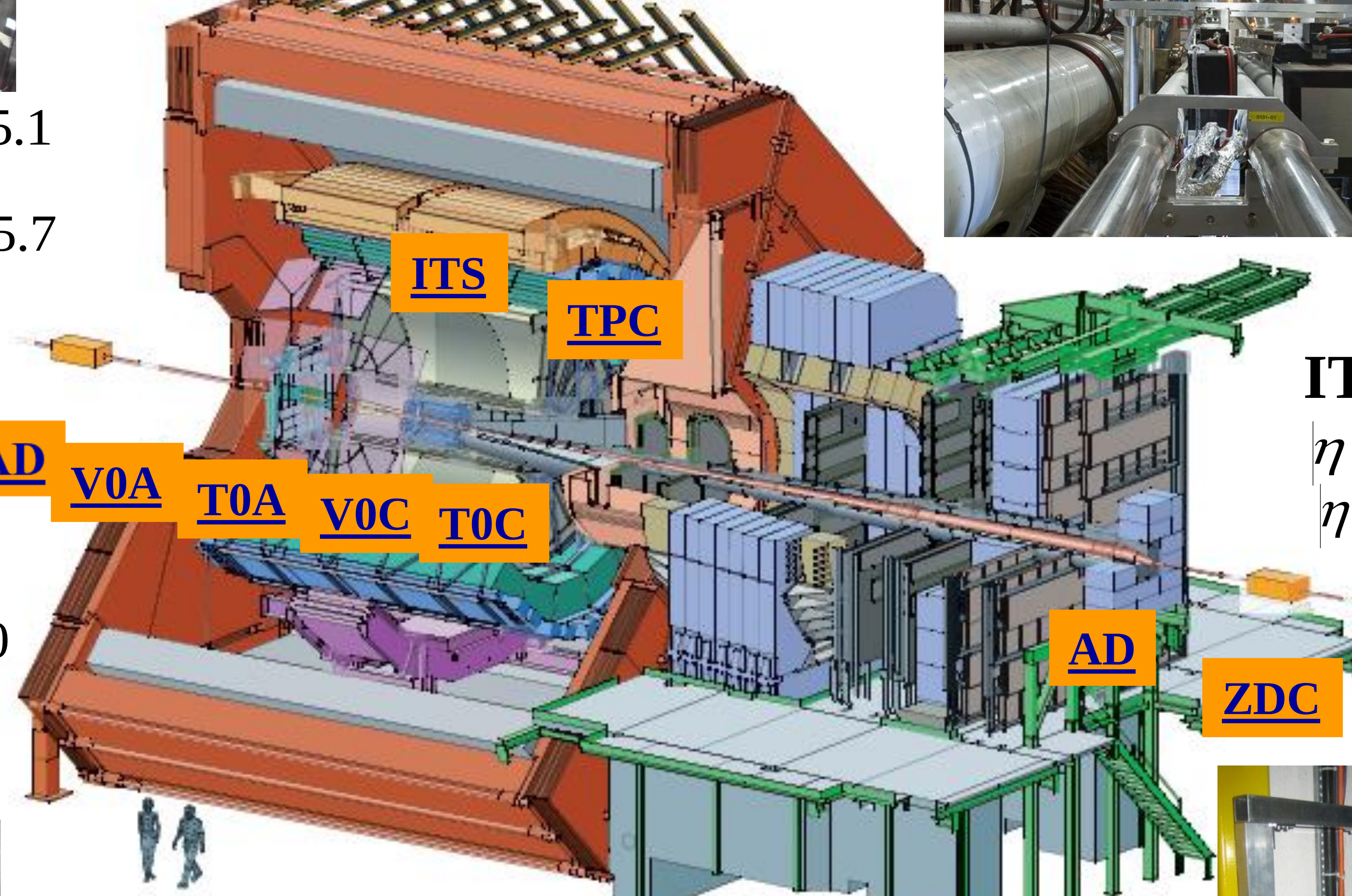
VZEROA



$2.8 < \eta < 5.1$

ZN $|\eta| > 8.7$ **ZP** $|\eta| > 8.4$

TPC $|\eta| < 0.9$

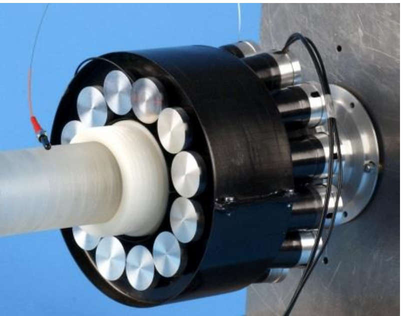


ZEM $4.8 < \eta < 5.7$

ITS
$|\eta| < 1.4$
$|\eta| < 2.0$

T0A $4.5 < \eta < 5.0$

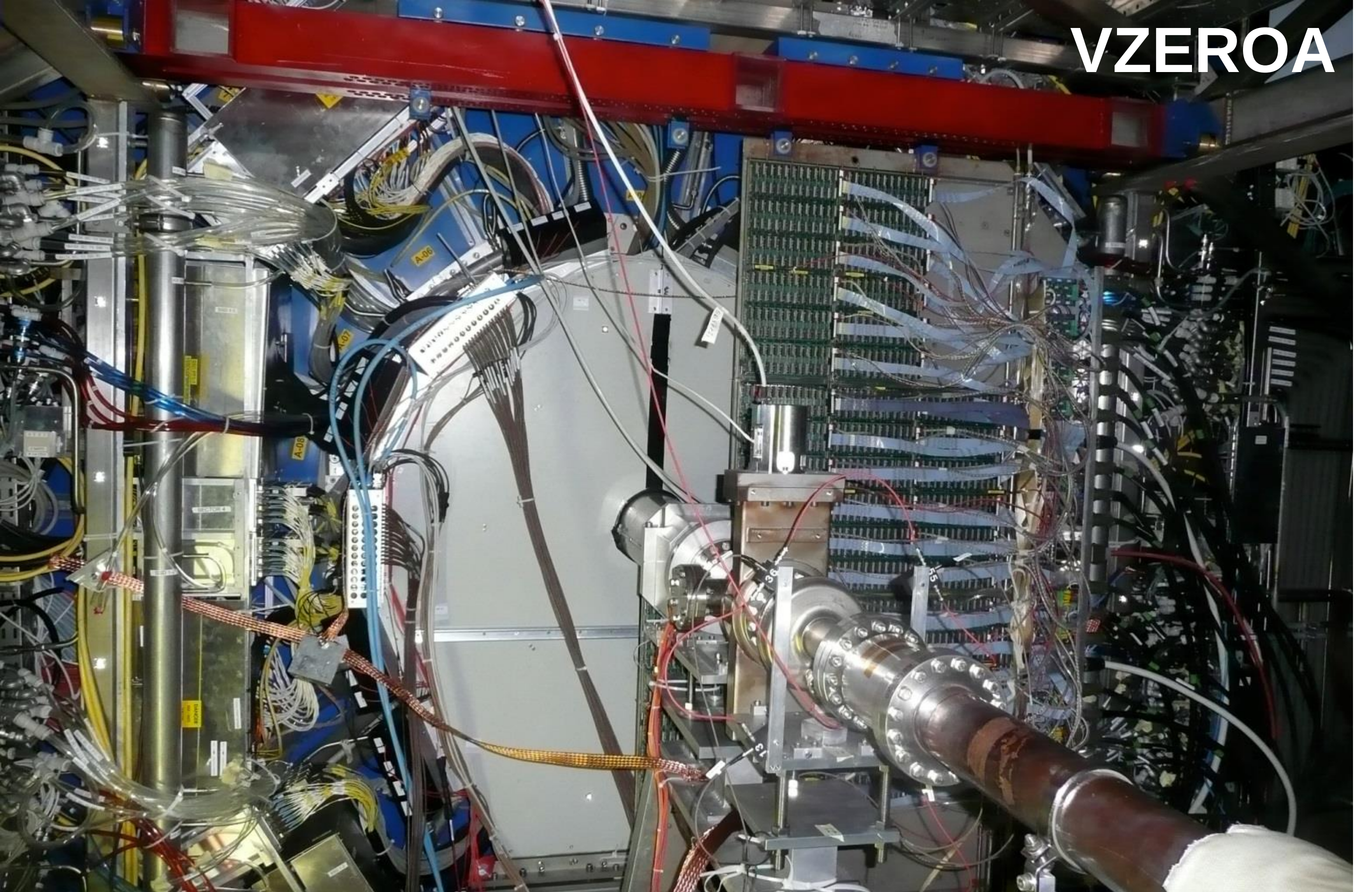
T0C
$-2.9 < \eta < -3.3$



VZEROC $-1.7 < \eta < -3.7$

FMD $1.7 < \eta < 5.0$ $-3.4 < \eta < -1.7$

ADD $-4.9 < \eta < -6.0$



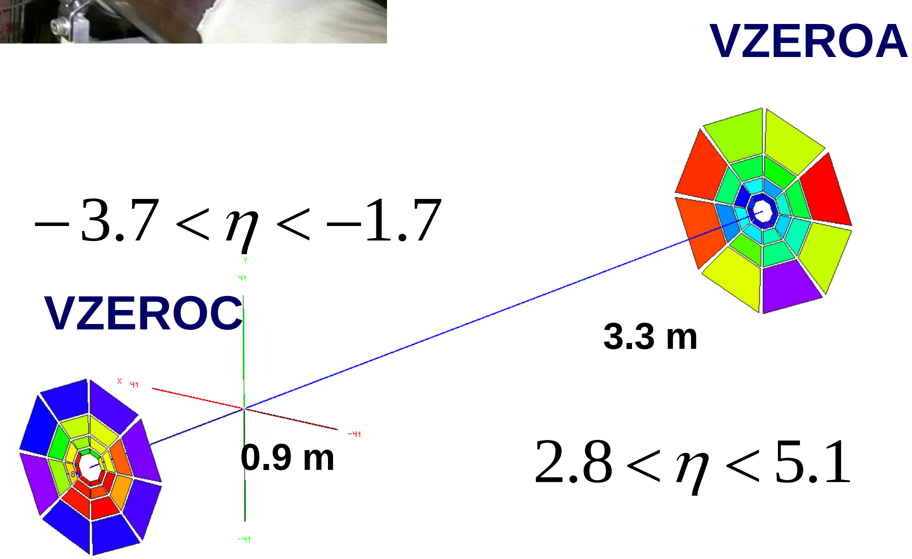
Trigger

Centrality measurement

Beam Gas suppresion

Event plane determination

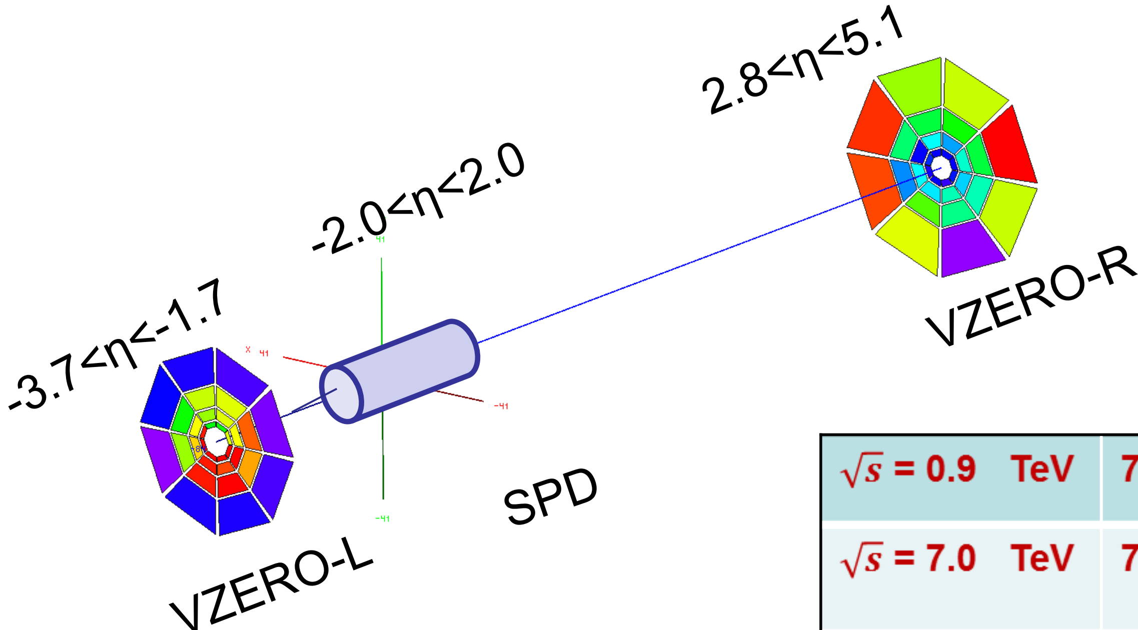
$$-3.7 < \eta < -1.7$$



$$2.8 < \eta < 5.1$$

Event samples

- Data at three energies : $\sqrt{s}$ = 0.9 2.76 7 TeV
- Low luminosity, low pile-up:
  average number of collisions per bunch crossing = 0.1
- Trigger used: Minimum Bias – OR i.e.
  at least one hit in SPD or VZERO
- VZERO signal should be in time with particles produced in the collisions



DATA

$\sqrt{s}$ = 0.9 TeV	7 $\times 10^6$ events
$\sqrt{s}$ = 7.0 TeV	75 $\times 10^6$ events
$\sqrt{s}$ = 2.76 TeV	23 $\times 10^6$ events

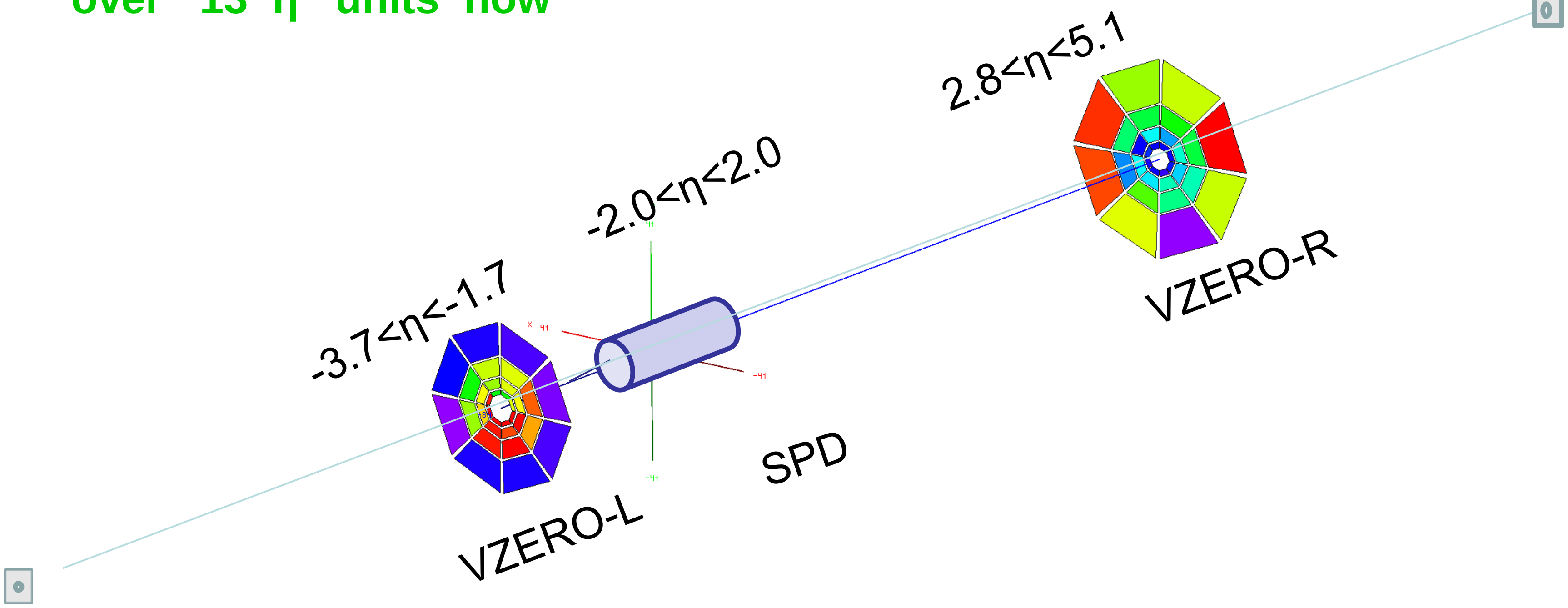
- Filled and empty bunch buckets used to measure beam induced background, accidentals due to electronics noise and cosmic showers

Minimum Bias Trigger - OR

ALICE Diffractive

over 8 η units before

over 13 η units now

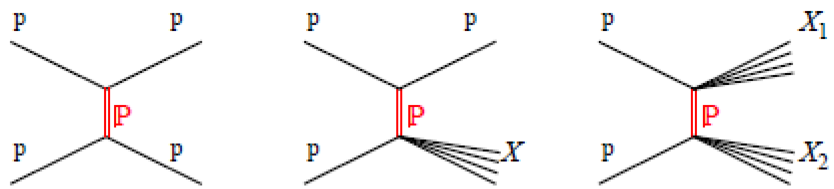


ALICE Diffractive   C-side

Summary of measurements on Diffractive Physics

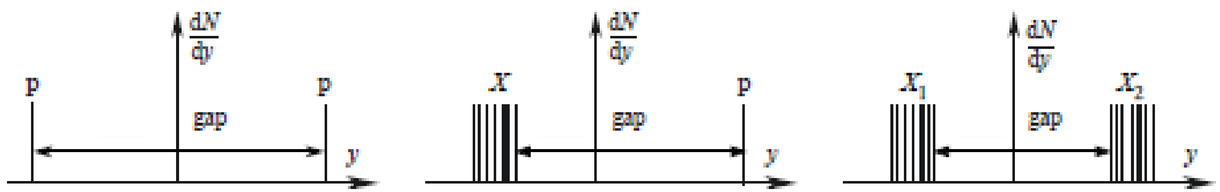
Measurements of Diffractive and Inelastic Cross Section

Eur. Phys.J. C73 (2013) 2456



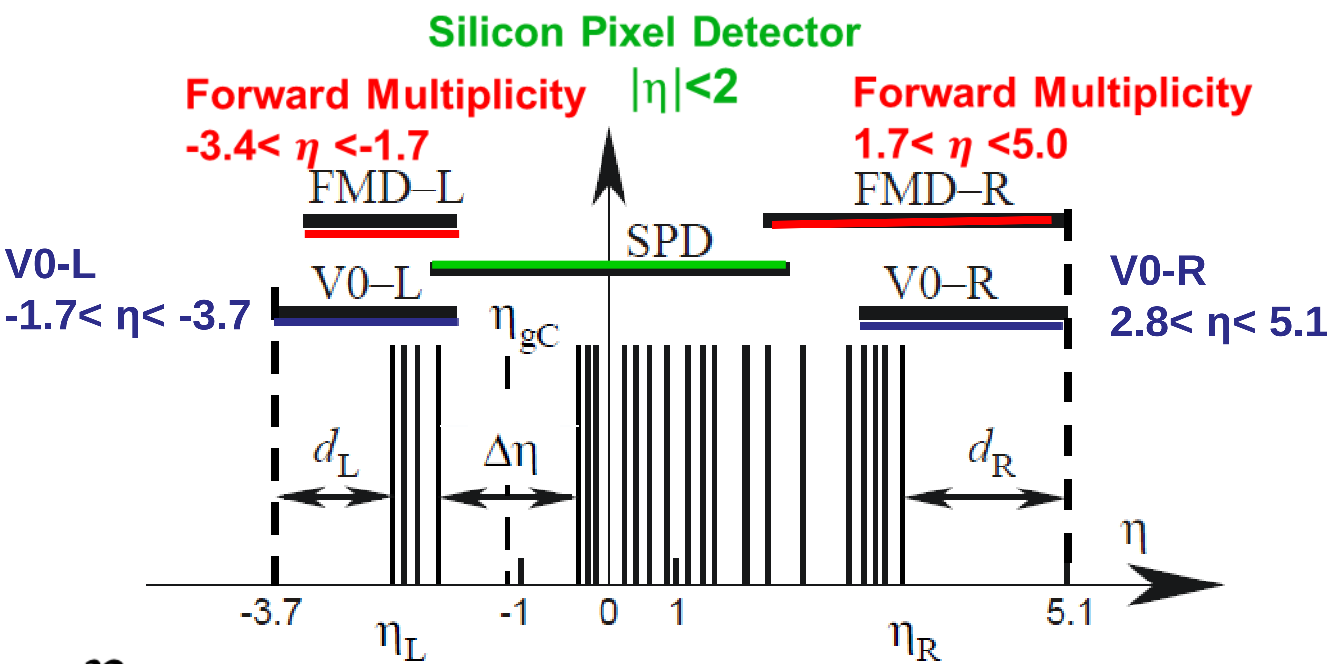
theory

elastic - single - double - diffractive proton-proton scattering



experiment

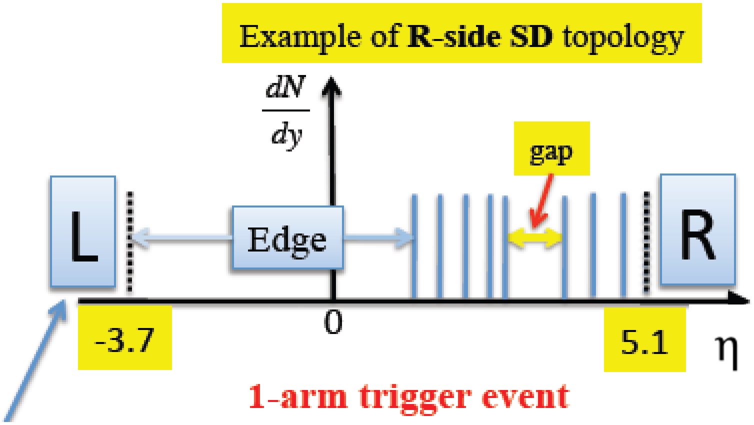
ALICE



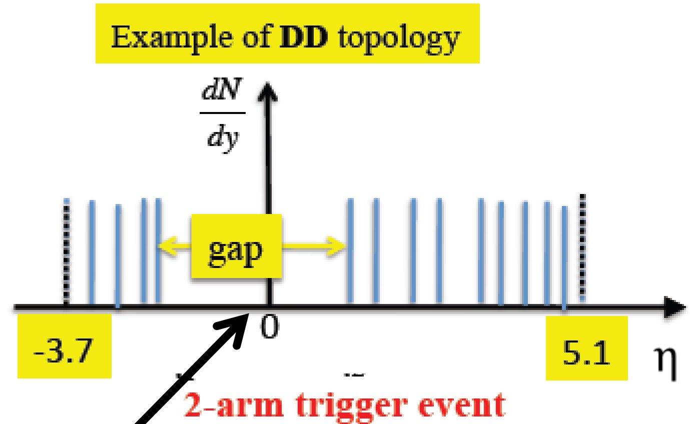
$$\eta_c = \frac{1}{2}(\eta_L + \eta_R)$$

η_L lowest- η_R highest - pseudorapidity

offline event clasification: "1 arm-L" "1 arm-R" "2 arm"



muon spectrometer



$$\eta_c = \frac{1}{2}(\eta_L + \eta_R)$$

$\eta_C < 0$	1-arm-L
$\eta_C > 0$	1-arm-R

if largest $\Delta\eta > d_L$ and d_R	2-arm
if both $-1 \leq \eta_L$ and $\eta_R \leq 1$	2-arm

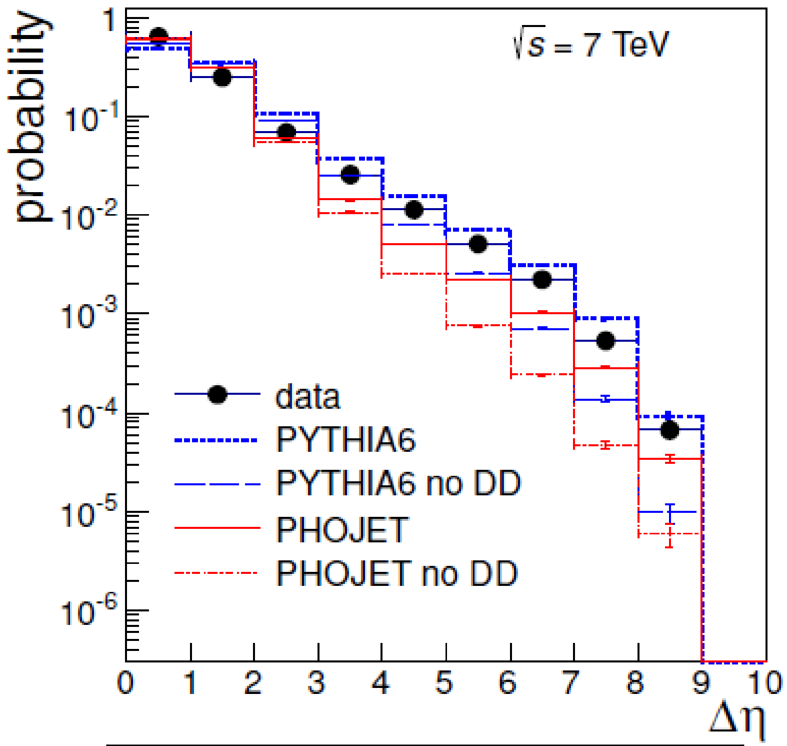
If $\eta_R < 1$	1-arm-L
If $\eta_L > -1$	1-arm-R

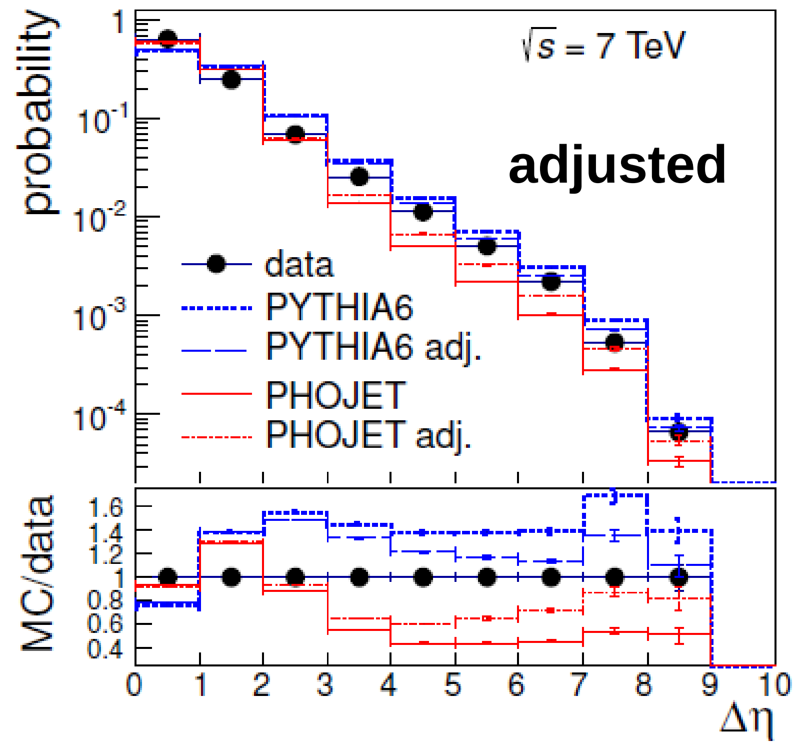
2-arm events

largest Δη

tuning PYTHIA and PHOJET double diffraction to experimental width distribution of two arm events

arXiv:1208.4968 [hep-ex]





$\sqrt{s}$ TeV	PYTHIA	PHOJET
0.9	0.12	0.06
7.0	0.13	0.05

$\sqrt{s}$ TeV	PHYTIA tuned	PHOJET tuned
0.9	0.10	0.11
7.0	0.09	0.07

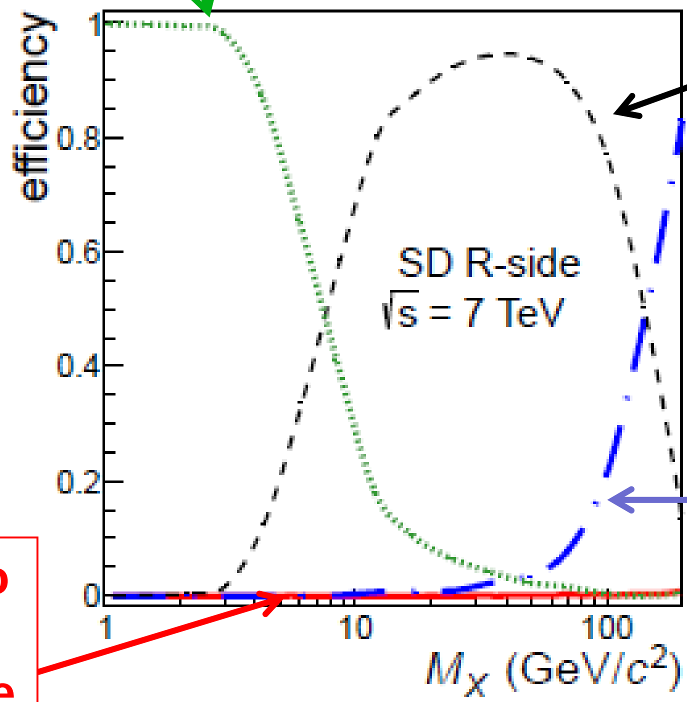
- **Once DD is chosen the ratios 1-arm-L and 1-arm-R to 2-arm can be used to compute SD fractions.**

- **efficiency/in-efficiency versus diffractive mass for SD :**

probability of not detecting

efficiency for a SD to be classified as 1-armL(R)

PYTHIA 6



efficiency to be classified as 2-arm

efficiency to be taken as the opposite

efficiencies used: mean between PYTHIA and PHOJET

efficiency of SD & NSD to be classified as 1-arm L(R), 2-arm

at high energy the ratio remains constant

$\sqrt{s}$ (TeV)	ratio definition	ratio	side	$\sigma_{SD}/\sigma_{INEL}$ per side	total
0.9	1-arm-L/2-arm	0.0576 ± 0.0002	L-side	0.10 ± 0.02	0.21 ± 0.03
	1-arm-R/2-arm	0.0906 ± 0.0003	R-side	0.11 ± 0.02	
2.76	1-arm-L/2-arm	0.0543 ± 0.0004	L-side	0.09 ± 0.03	$0.20^{+0.07}_{-0.08}$
	1-arm-R/2-arm	0.0791 ± 0.0004	R-side	$0.11^{+0.04}_{-0.05}$	
7	1-arm-L/2-arm	0.0458 ± 0.0001	L-side	$0.10^{+0.02}_{-0.04}$	$0.20^{+0.04}_{-0.07}$
	1-arm-R/2-arm	0.0680 ± 0.0001	R-side	$0.10^{+0.02}_{-0.03}$	

consistent with UA5 $p\,\bar{p}$

results symmetric despite different acceptance from ALICE

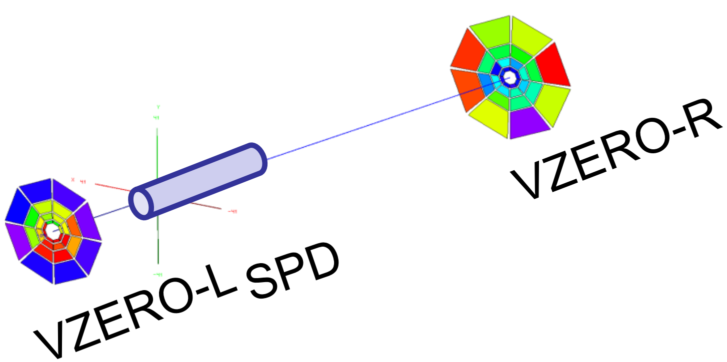
corrected for acceptance, efficiency, beam background, electronic noise and collision pileup

DD events defined as NSD with large gap

$\sqrt{s}$ (TeV)	$\sigma_{DD}/\sigma_{INEL}$
0.9	0.11 ± 0.03
2.76	0.12 ± 0.05
7	$0.12^{+0.05}_{-0.04}$

with $\Delta\eta > 3$

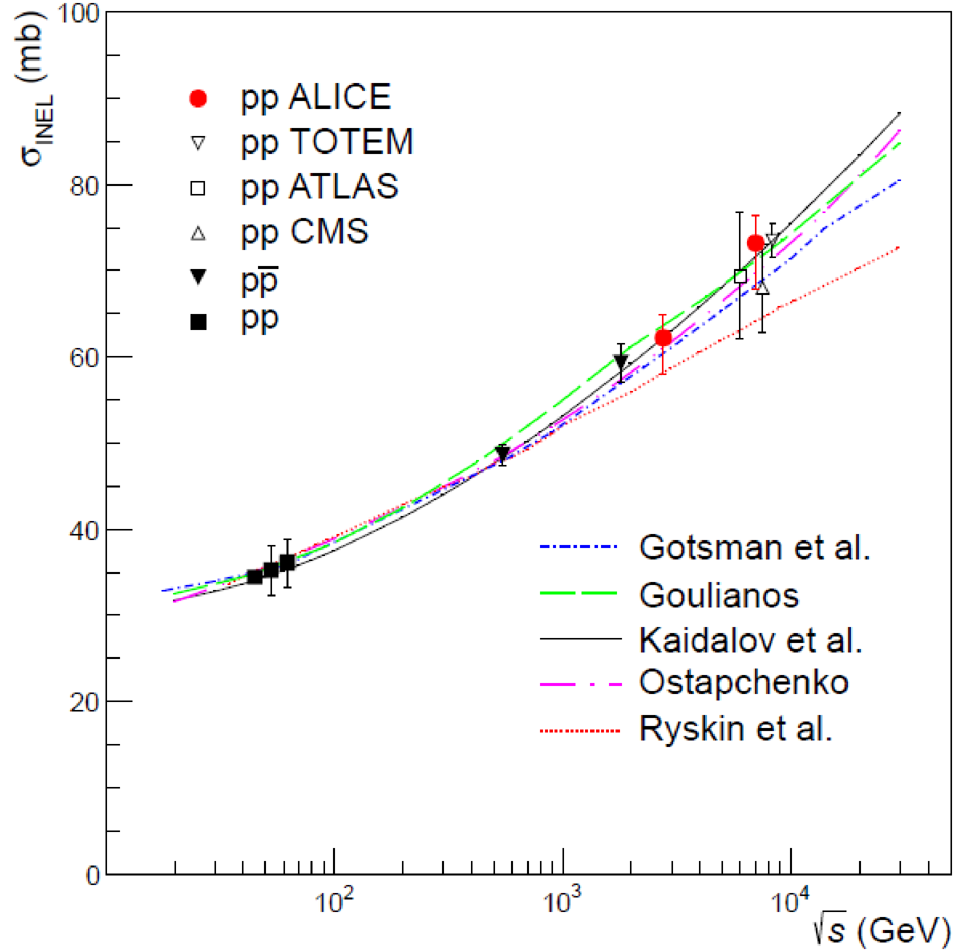
Measurement of Inelastic Cross Section



MB-and : coincidence of VZERO-L and –R in a van der Meer scan

$$\frac{dN(MBand)}{dt} = A \times \sigma_{inel} \times L$$

acc. and eff. determined with adjusted simulation



Experiment	σ_{INEL} (mb)
ALICE	$73.2^{+2.0}_{-4.6}(model) \pm 2.6(lumi)$
ATLAS [19]	$69.4 \pm 6.9(model) \pm 2.4(exp)$
CMS [20]	$68.0 \pm 4.0(model) \pm 2.0(syst) \pm 2.4(lumi)$
TOTEM [21]	$73.5^{+1.8}_{-1.3}(syst) \pm 0.6(stat)$

Measurements of Diffractive Cross Section

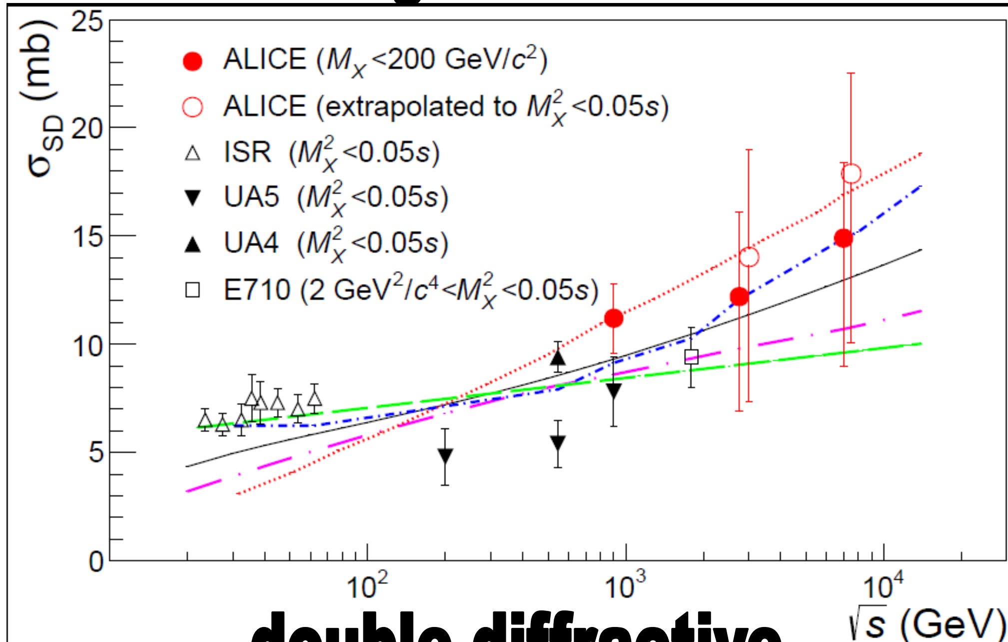
with inelastic cross section and relative rates we obtain SD and DD cross sections

for $\sqrt{s} = 0.9\ TeV$ we do not have vdM scan and σ_{inel} from UA5 was used

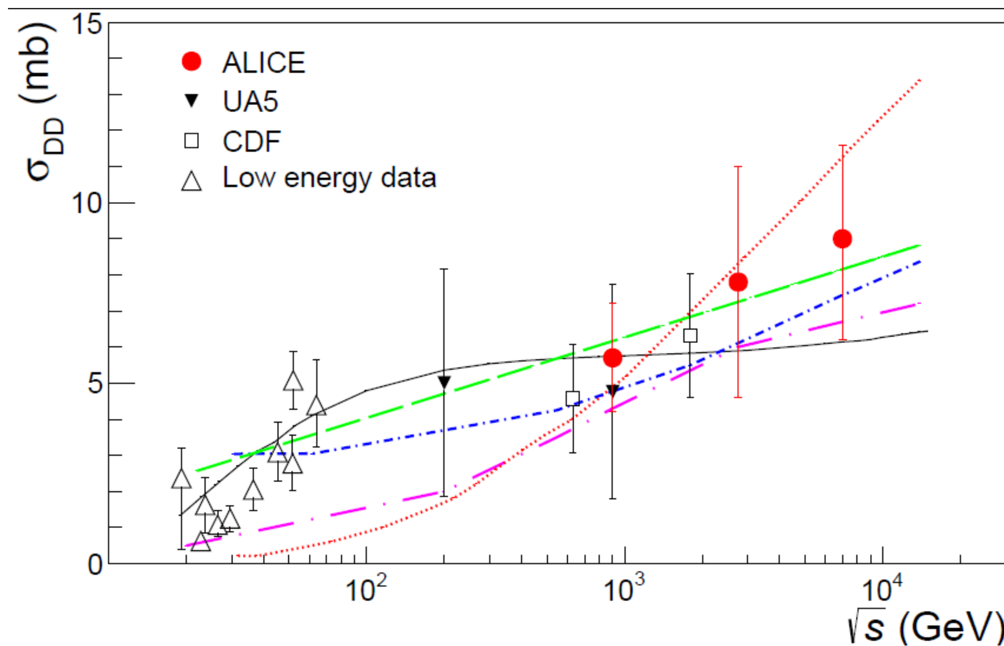
$$\sigma_{INEL} = 52.5^{+2}_{-3.3}\ mb$$

- - · - - · - Gotsman et al.
- - - - - - Goulianos
———— Kaidalov et al.
- · - · - Ostapchenko
········ Ryskin et al.

single diffractive



double diffractive

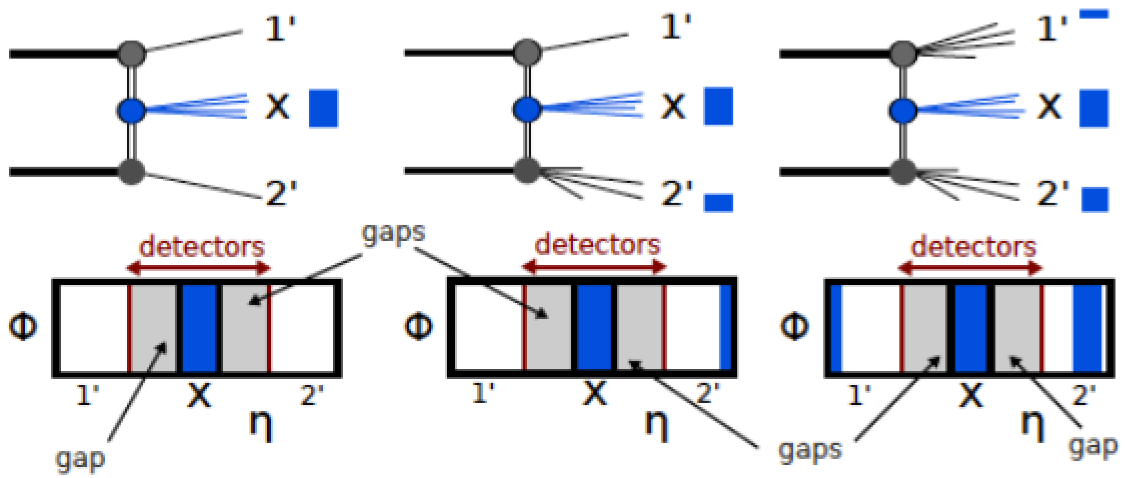


Central Diffractive Physics

Central diffraction in proton proton collisions at $\sqrt{s}$ = 7 TeV

Double Gap topology as a filter for Central Diffraction

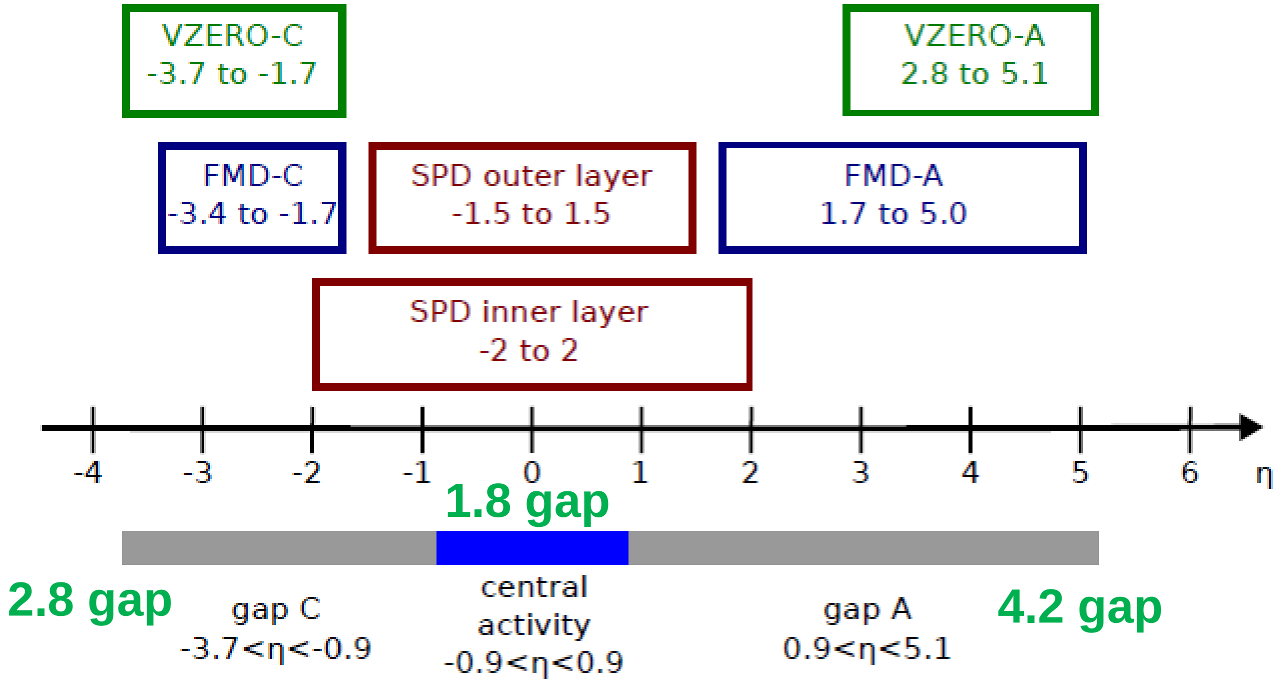
Central Diffraction | **CD with single Diffractive dissociation** | **CD with double Diffractive dissociation**



Low mass central diffractive final states decaying into a small number of particles production of meson states: glueballs, hybrids,

A search for structure in the mass spectra of exclusive decays such as $\pi^+ \pi^-$ $K^+ K^-$ $2\pi^+ 2\pi^-$ $K^+ K^- \pi^+ \pi^-$ etc.

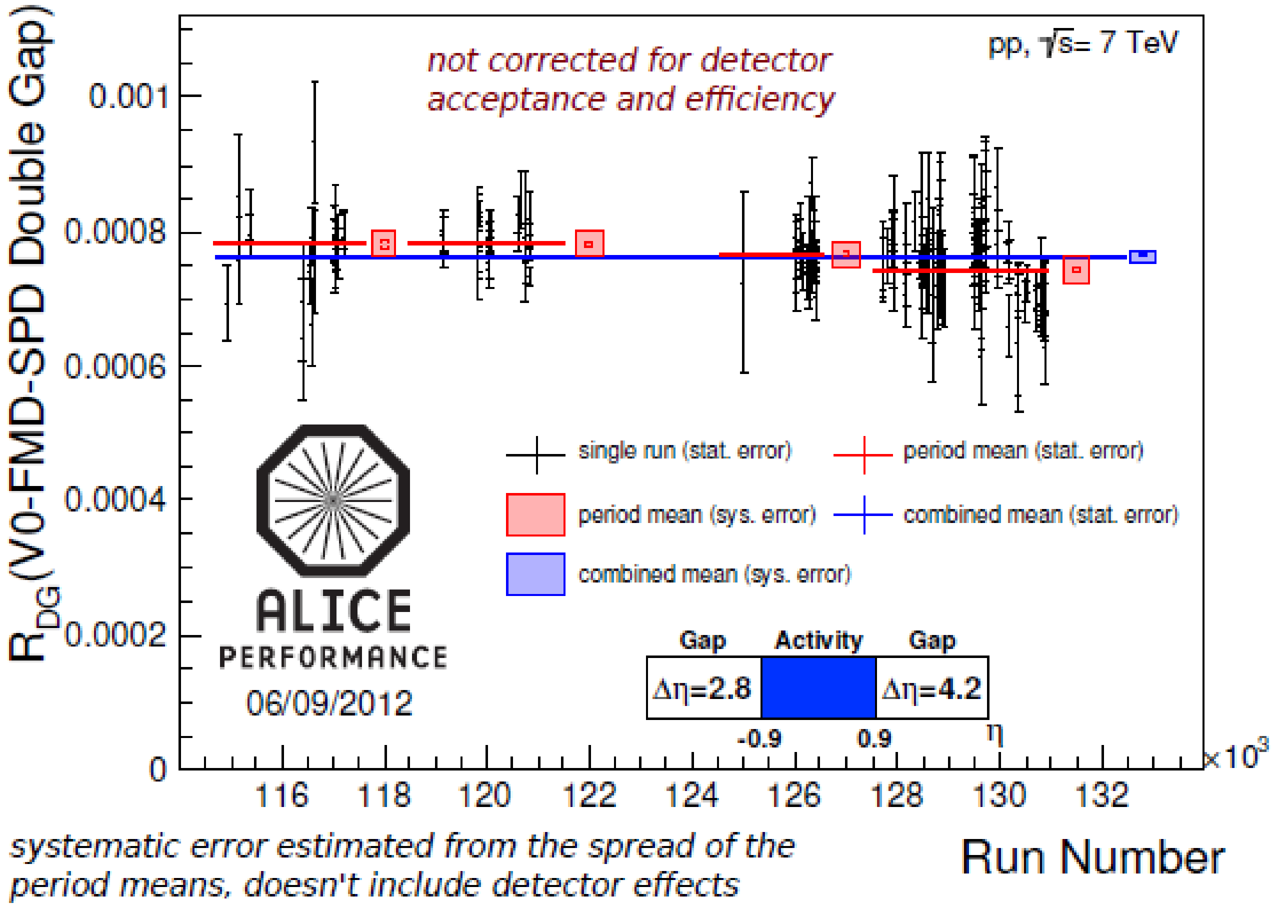
Double Gap topology



$$N_{DG} = \frac{\text{Number of Double Gap events}}{\text{Number of VZERO-L –R coincidence}}$$

Potential measure of the amount of Central Diffractive events in Minimum Bias data

Double Gap fraction in proton proton $\sqrt{s} = 7\ TeV$



- fraction uniform over several data taking periods

Next:

turn it into a cross section

$$\frac{N_{DG}}{N_{\text{MBand}}} = (7.63 \pm 0.02(stat.) \pm 0.95(syst.)) \cdot 10^{-4}$$

we are exploring the invariant mass distribution

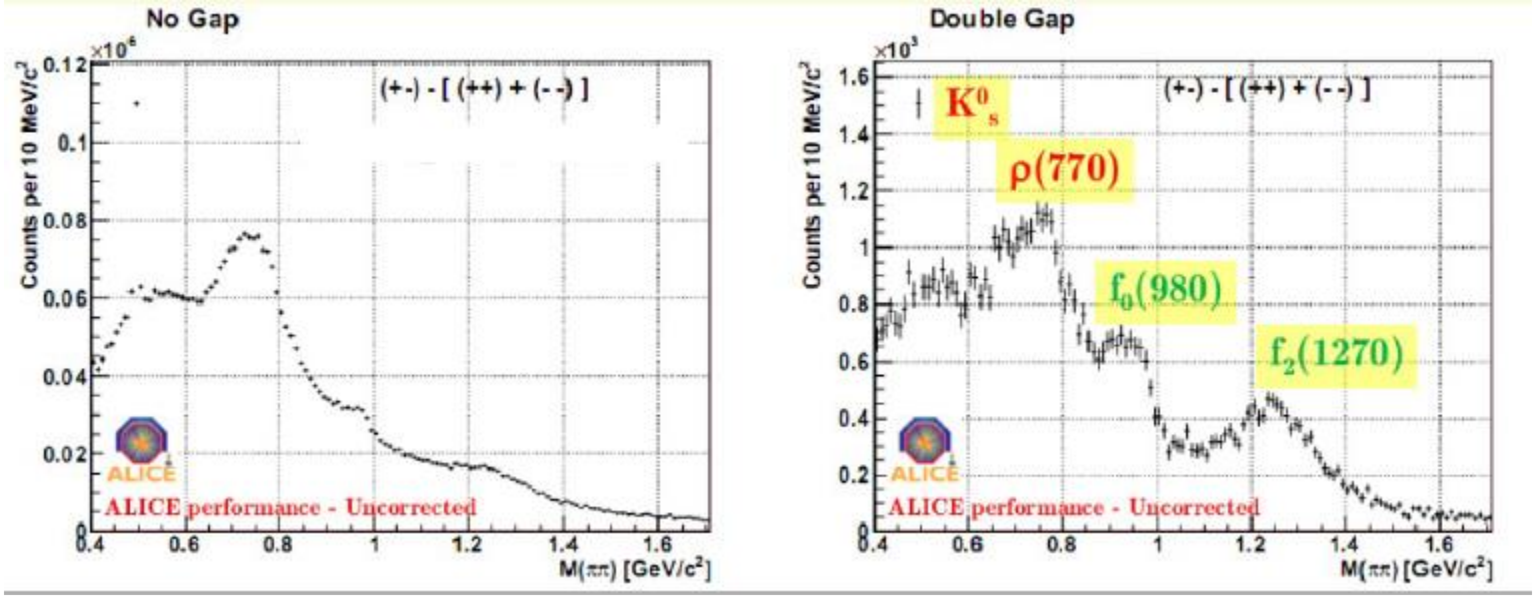
2011 data

361 M events with the Minimum Bias Trigger

32.3 M events with primary vertex and exactly 2 tracks in the TPC+ITS

29.2 M events with no gaps

Exclusive resonance production in proton proton at 7 TeV cms

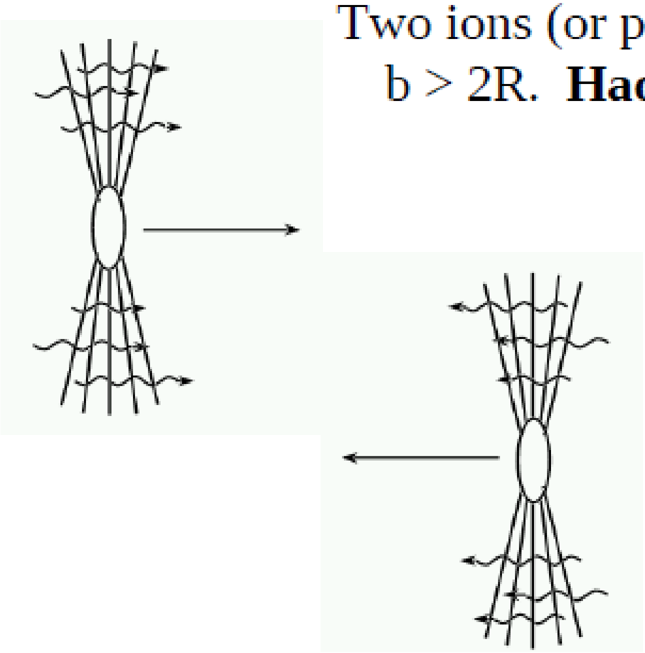


M_{inv} for two track events
with-out gaps.

M_{inv} for two track events
with gaps on both sides

Studies in Ultra Peripheral Colisions

Two ions (or protons) pass by each other with impact parameters b > 2R. **Hadronic interactions are strongly suppressed**



Number of photons scales like Z^2 for a single source ⇒ exclusive particle production in heavy-ion collisions dominated by electromagnetic interactions.

The virtuality of the photons → 1/R ~ 30 MeV/*c*

Coherent production:

Photon couples coherently to all nucleons

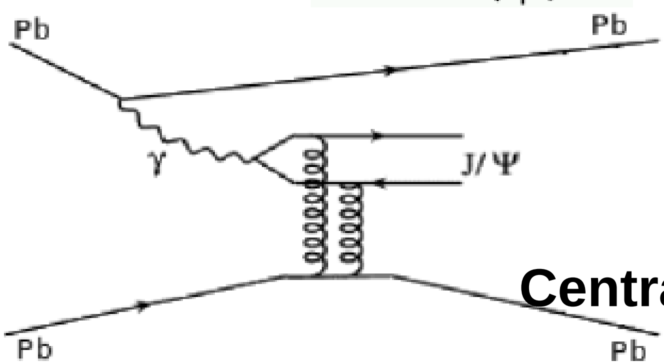
$\langle p_T \rangle \sim 60$ MeV/*c*; target nucleus normally does not break up

Incoherent production

Photon couples to a single nucleon

Quasi-elastic scattering off a single nucleon

$\langle p_T \rangle \sim 500$ MeV/*c*



Central rapidity

A big jump in energy ...

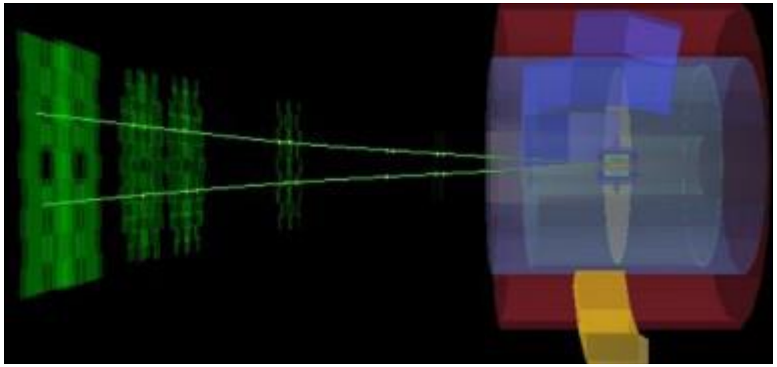
RHIC: $W_{\gamma N,max} \sim 34$ GeV

HERA: $W_{\gamma N,max} \sim 300$ GeV

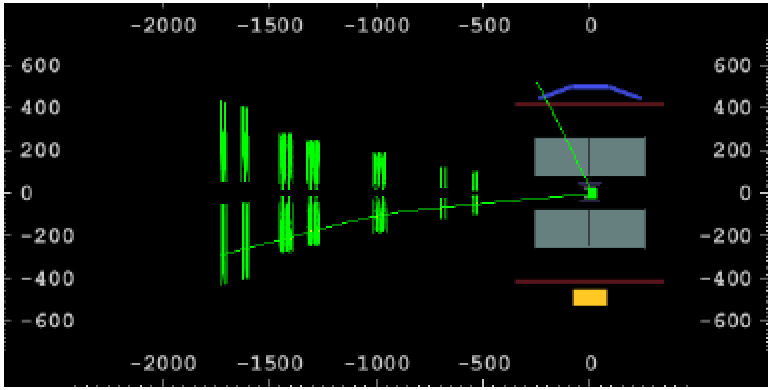
LHC: $W_{\gamma N,max}$ reaches up to 950 GeV !

$\gamma + p \rightarrow J/\psi + p$

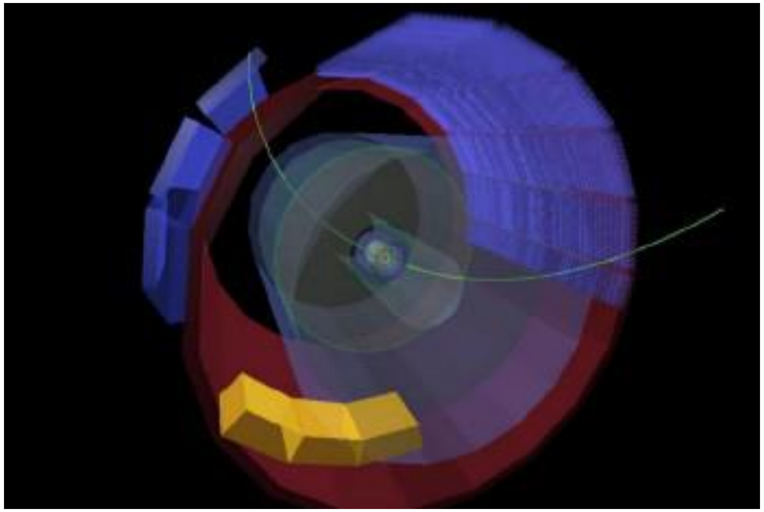
modelled in pQCD: exchange of two gluons with no net-colour transfer



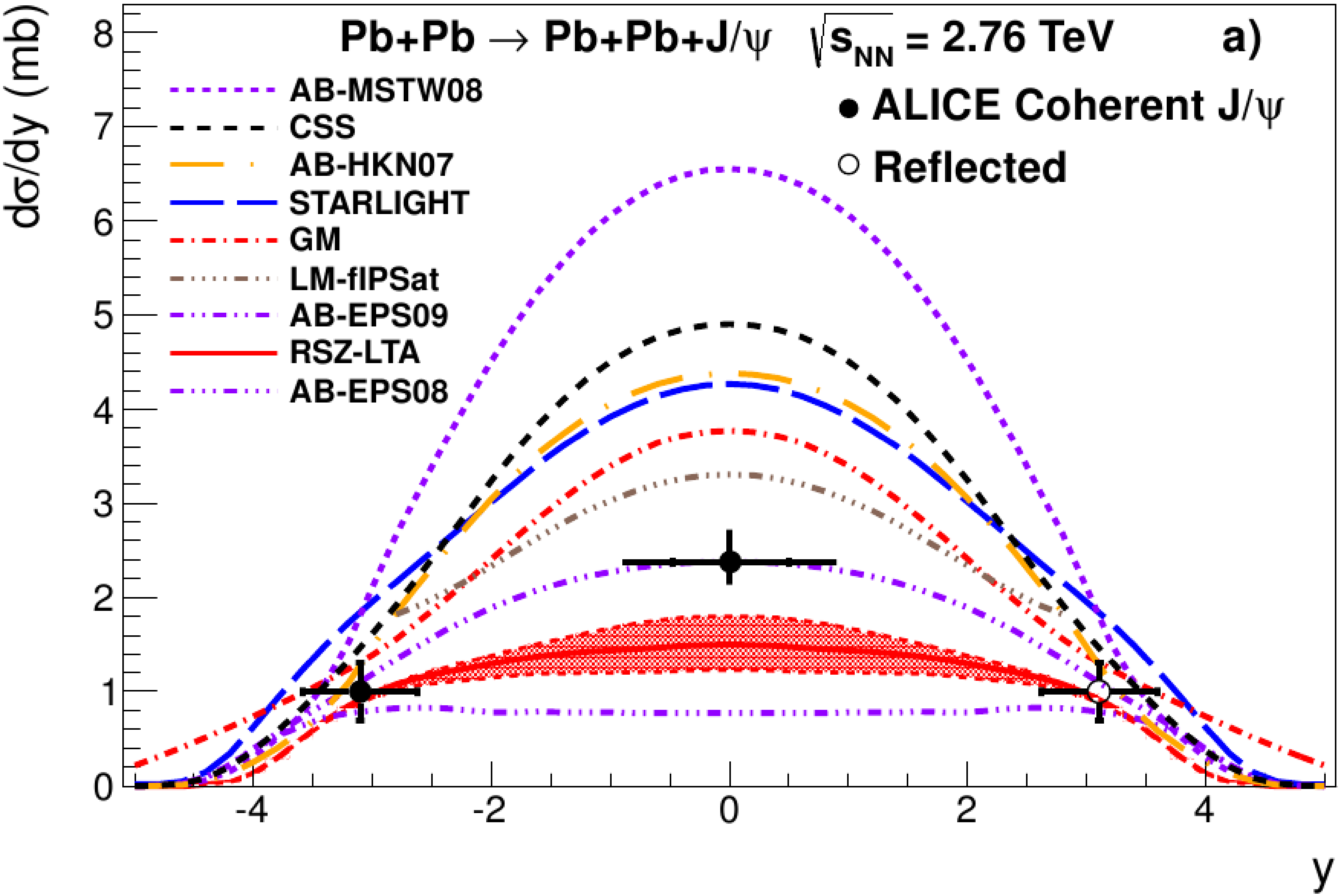
two muons in the muon arm



one muon in the muon arm one in the barrel



two muons in the barrel

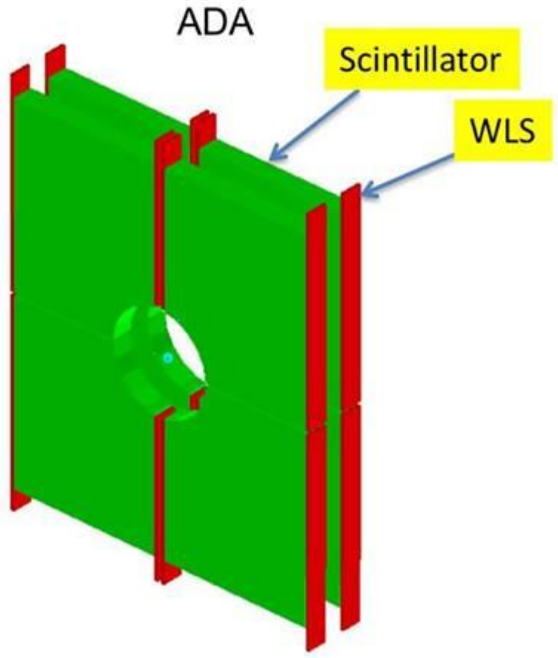


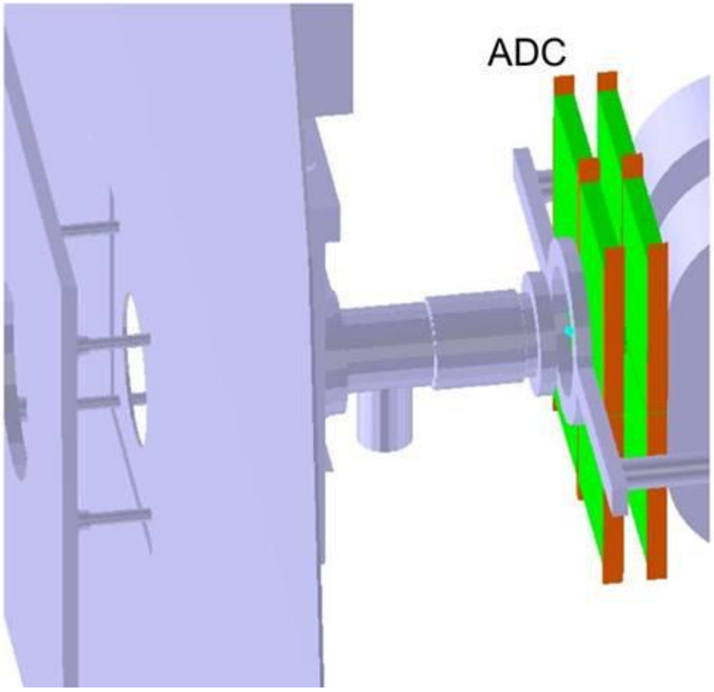
In agreement with models that include moderate gluon shadowing:

AB EPS09 parametrization

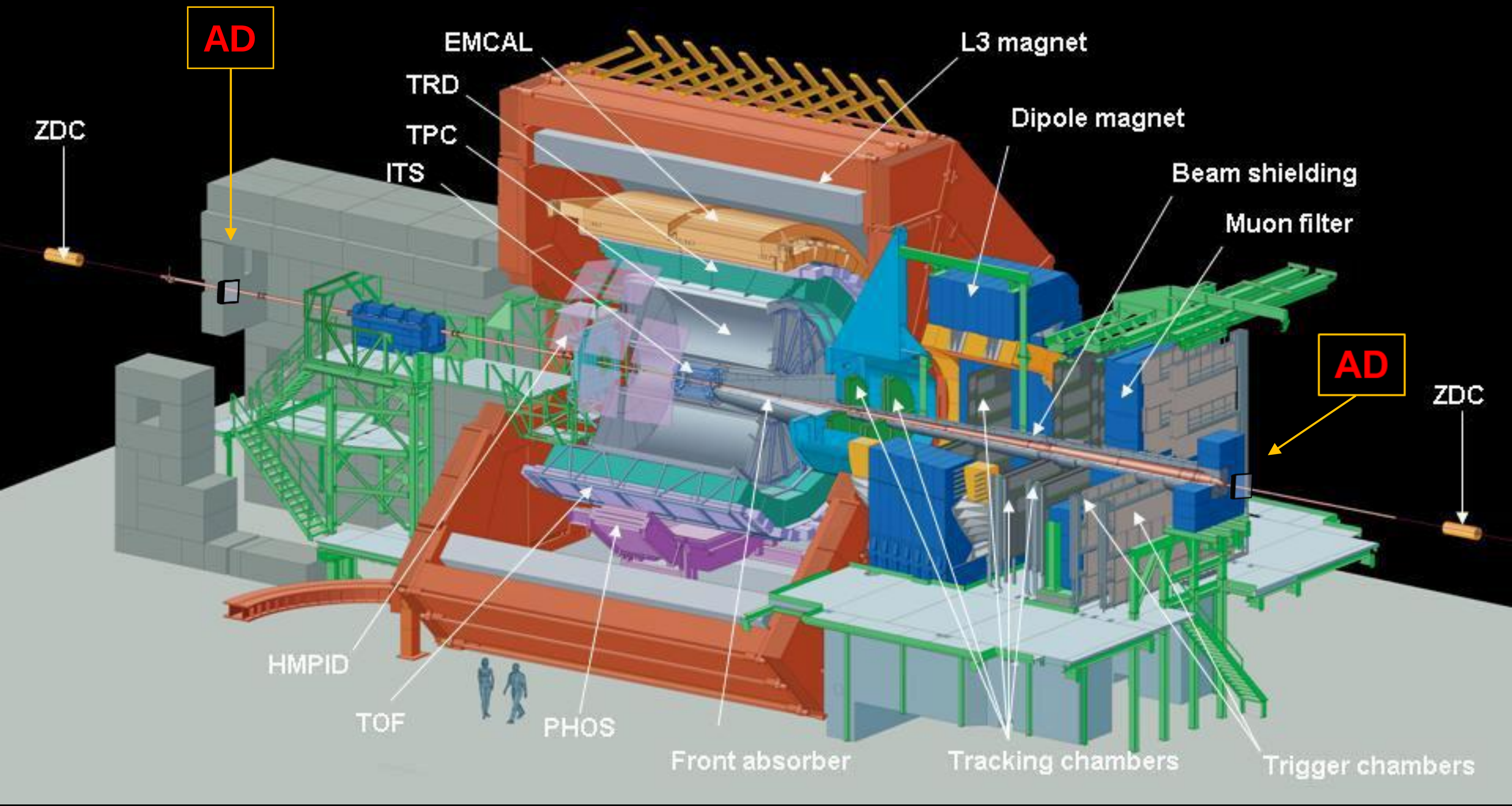
A LICE D iffractive Detector for Run 2

A new sub-system for diffractive physics, bringing the total number of sub-detectors which make up ALICE to 19

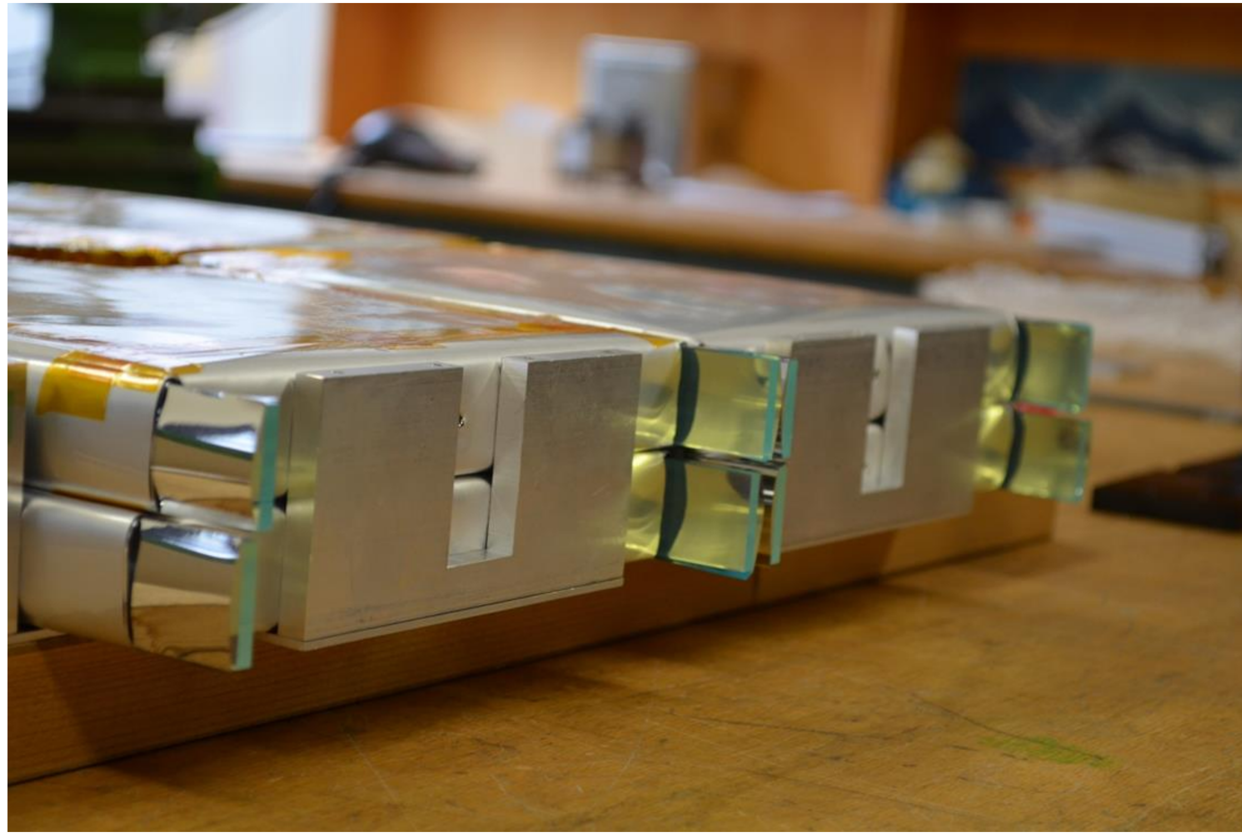
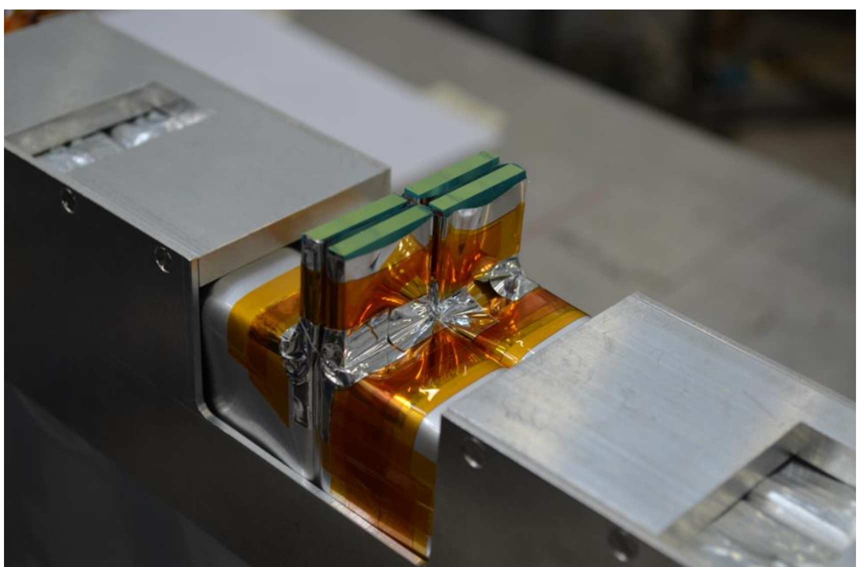
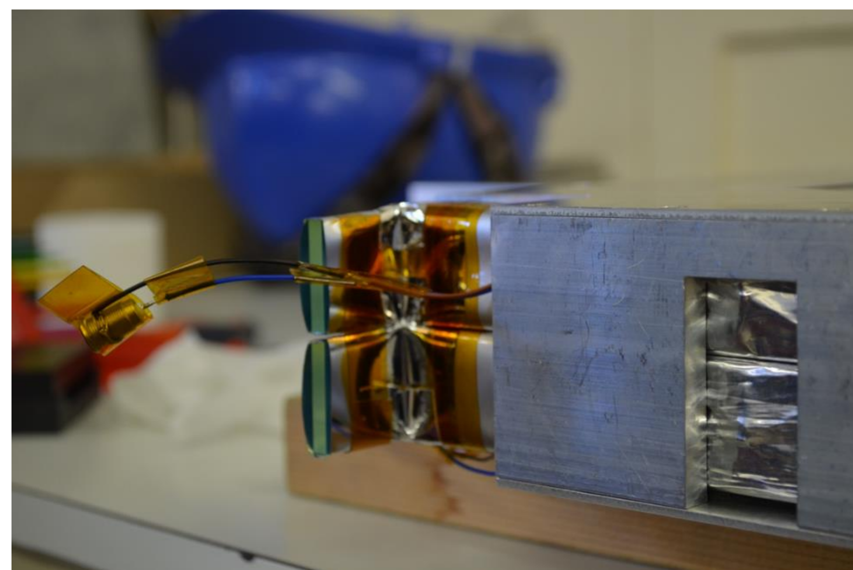




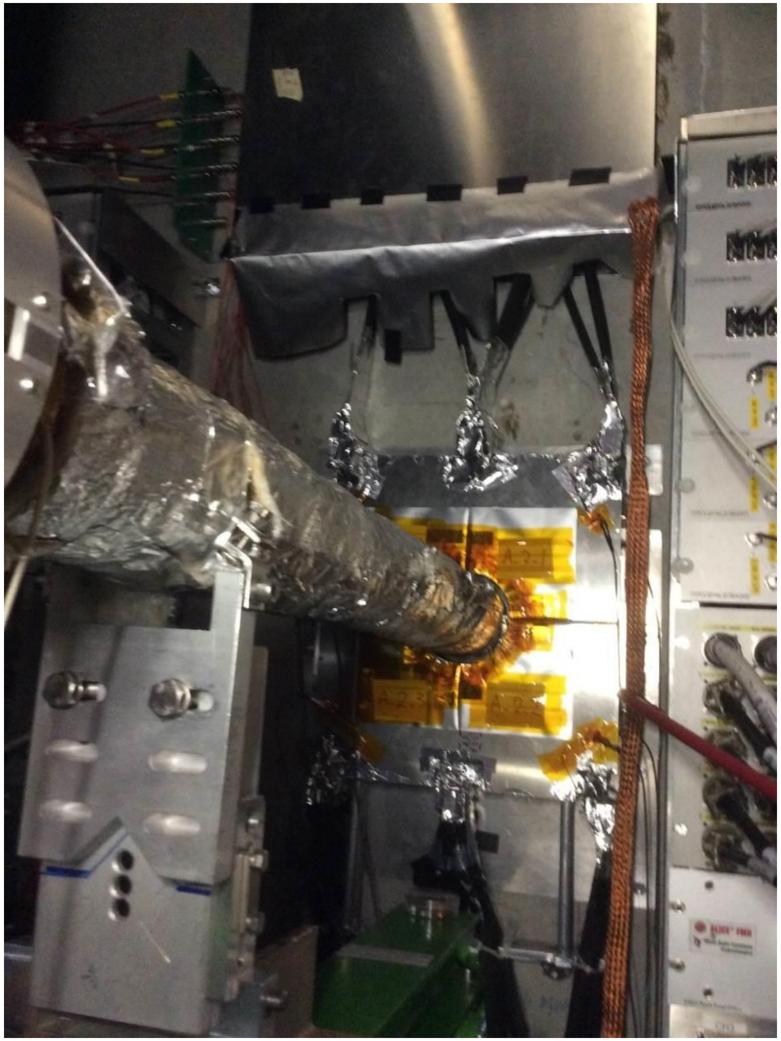
ALICE



the 19th system of ALICE

Final position
A side

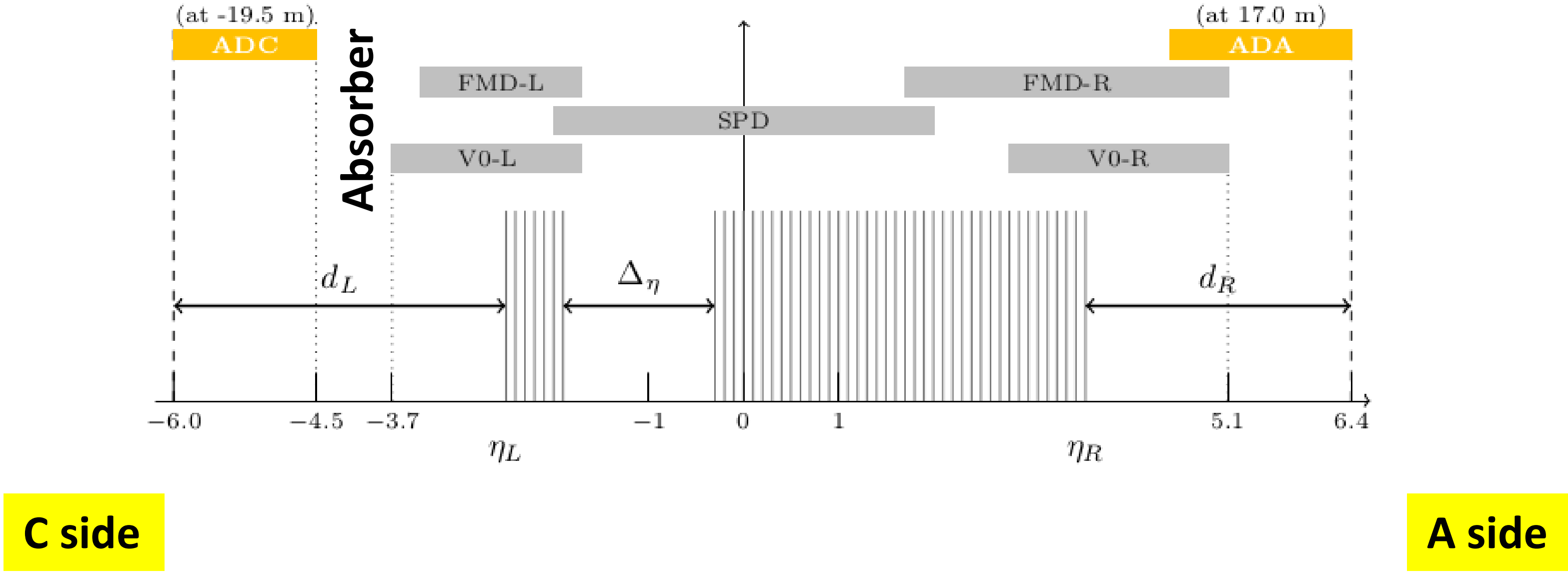


ADA/ADC layer positions

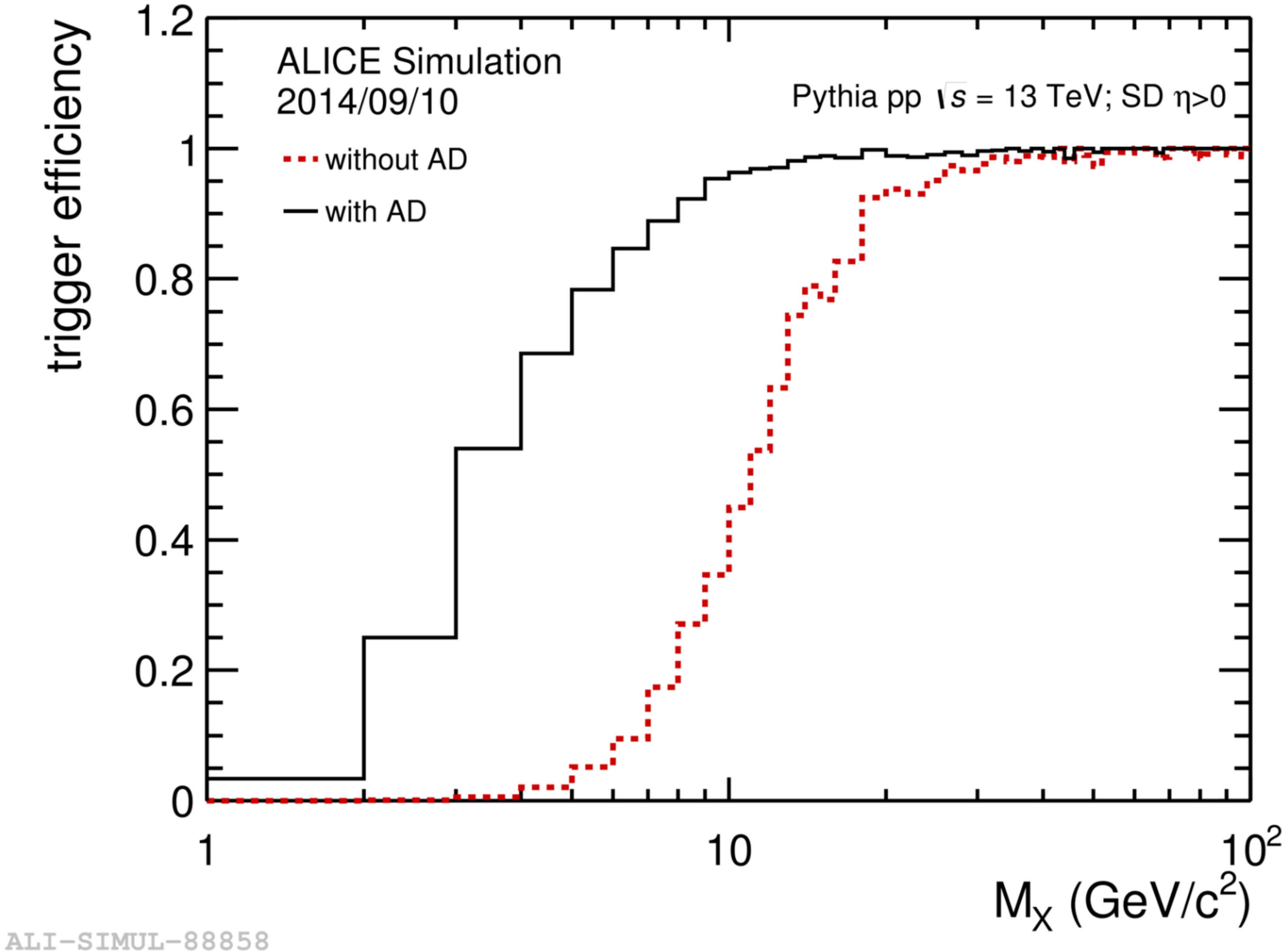
Station	Inner radius (cm)	η_{min}	η_{max}	Z (cm)
ADC layer 0	3.7	-6.96	-4.92	-1955.75
ADC layer 1	3.7	-6.96	-4.92	-1953.05
ADA layer 2	6.2	+4.77	+6.30	+1693.65
ADA layer 3	6.2	+4.77	+6.30	+1696.35

Run 2: Diffraction (SD and DD)

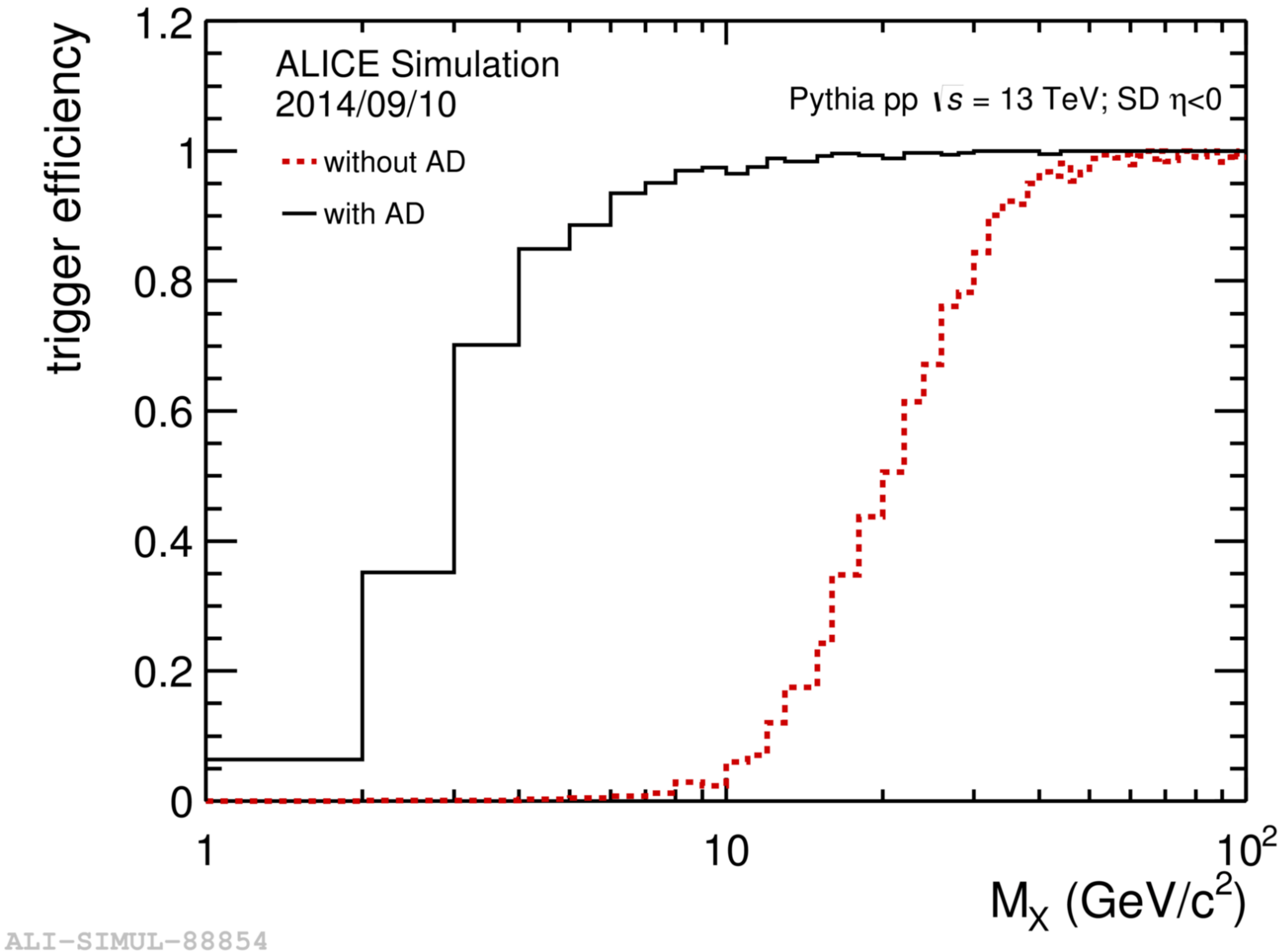
ADA and ADC counters increase the **pseudorapidity coverage from 8.8 to 13.2**



Integration of AD-L and AD-R in ALICE would enhance considerably the efficiency at low diffractive mass.



Integration of AD-L and AD-R in ALICE would enhance considerably the efficiency at low diffractive mass.



VZERO, SPD & FMD
VZERO, SPD & FMD+2 stations
VZERO, SPD & FMD+4 stations

PHOJET 7 TeV

trigger	Efficiency Pure–events (%)	Efficiency Minimum–Bias (%)	Purity (%)
$SD\text{-}L_0$	13.14	1.26	71.44
$SD\text{-}L_1$	27.66	2.25	84.33
$SD\text{-}L_2$	31.15	2.45	87.48
$SD\text{-}R_0$	19.68	1.98	68.45
$SD\text{-}R_1$	30.92	2.55	83.17
$SD\text{-}R_2$	33.47	2.66	86.57
DD_0	4.69	0.45	51.57
DD_1	13.60	0.99	68.37
DD_2	16.35	1.14	71.37
CD_0	3.28	0.11	55.55
CD_1	3.11	0.06	97.29
CD_2	3.10	0.06	98.73

PYTHIA 6 7 TeV

trigger	Efficiency Pure–events(%)	Efficiency Minimum–Bias (%)	Purity (%)
$SD\text{-}L_0$	11.30	1.80	59.95
$SD\text{-}L_1$	26.38	3.23	78.18
$SD\text{-}L_2$	31.54	3.56	84.84
$SD\text{-}R_0$	16.73	2.96	54.08
$SD\text{-}R_1$	29.05	3.76	74.01
$SD\text{-}R_2$	32.93	3.85	81.84
DD_0	5.31	1.00	64.96
DD_1	16.80	2.63	78.43
DD_2	21.93	3.28	82.15

PYTHIA 6 7 TeV

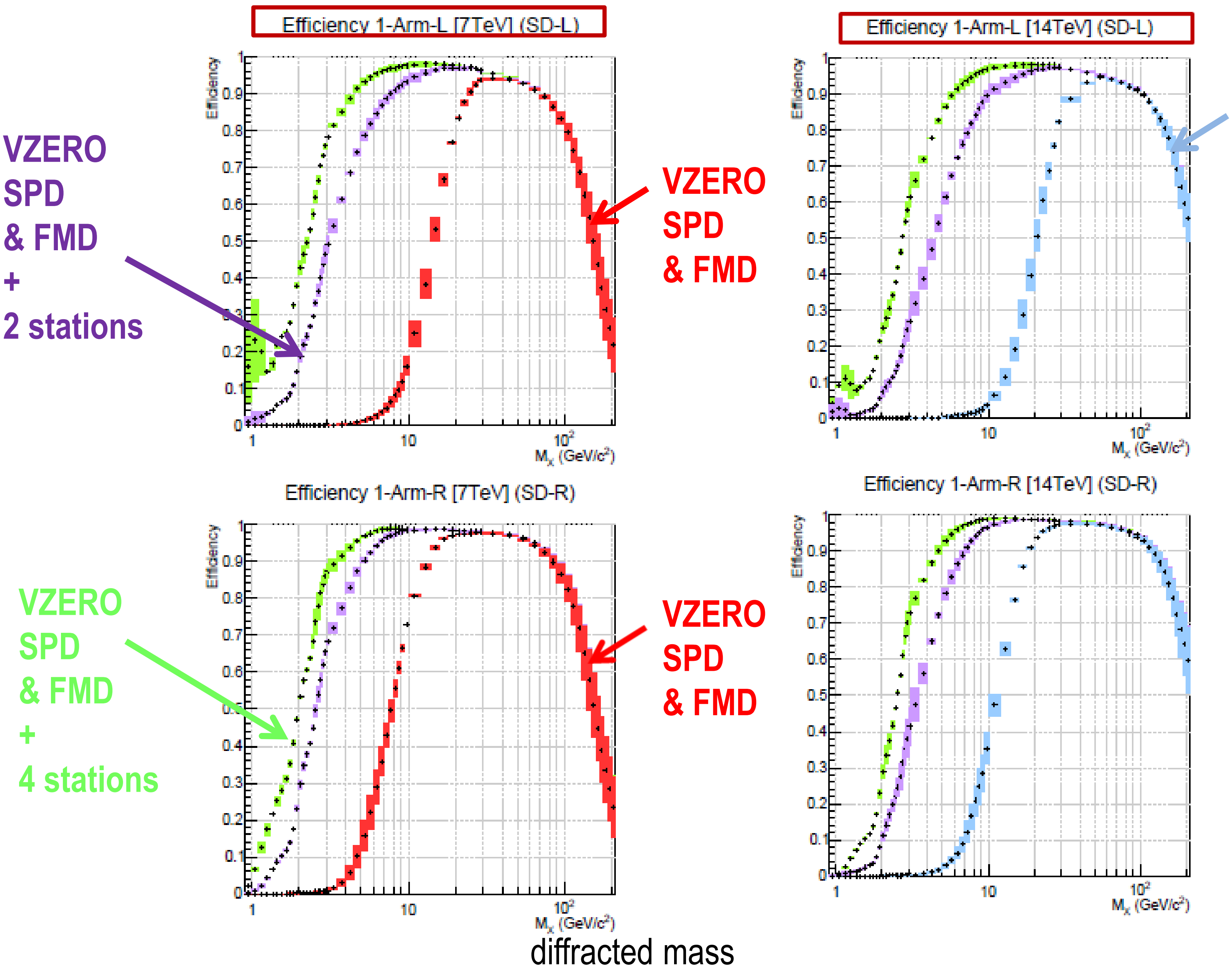
trigger	Efficiency Pure–events(%)	Efficiency Minimum–Bias(%)	Purity (%)
1–Arm–L_0	23.61	3.87	58.36
1–Arm–L_1	38.60	4.77	77.42
1–Arm–L_2	41.25	4.71	83.84
1–Arm–R_0	30.23	5.79	49.93
1–Arm–R_1	40.96	5.49	71.37
1–Arm–R_2	42.79	5.17	79.14

VZERO, SPD & FMD
VZERO, SPD & FMD+2 stations
VZERO, SPD & FMD+4 stations

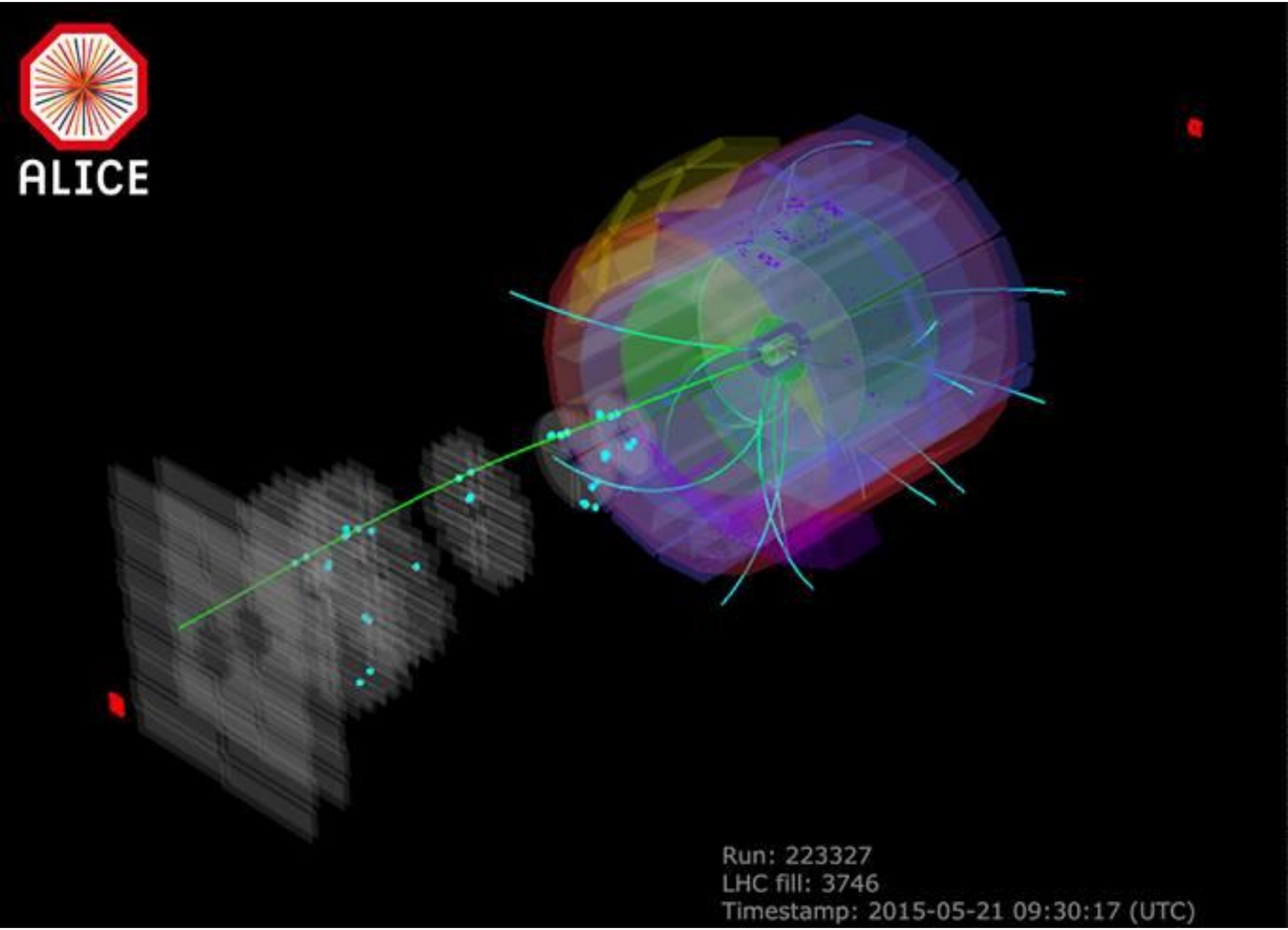
PHOJET 7 TeV

trigger	Efficiency Pure–events(%)	Efficiency Minimum–Bias(%)	Purity(%)
1–Arm–L_0	27.01	2.87	64.67
1–Arm–L_1	41.38	3.67	77.37
1–Arm–L_2	44.85	3.82	80.59
1–Arm–R_0	35.10	3.97	60.73
1–Arm–R_1	46.00	4.19	75.49
1–Arm–R_2	48.53	4.21	79.17

As defined in the recent paper: arXiv:1208.4968 accepted in Eur. Phys. J. C



the boxes indicate the difference between pythia6 & phojet


ALICE
Run: 223327
LHC fill: 3746
Timestamp: 2015-05-21 09:30:17 (UTC)

ALICE upgrade

- luminosity upgrade – 50 kHz for Pb–Pb collisions and 2 MHz in pp
- improved vertex measurement and tracking at low p_T
- preserve particle-identification capability
- high-luminosity operation without dead-time
- new, smaller radius beam pipe
- new inner tracker (ITS) (performance and rate upgrade)
- high-rate upgrade for the readout of the TPC, TRD, TOF, CALs, DAQ-HLT, Muon-Arm and Trigger detectors
- Muon Forward Tracker (MFT)
- Forward Calorimeter (FoCal)

- target for installation and commissioning LS2 (2018)
- collect more than 10 nb^{-1} of integrated luminosity
  - implies running with heavy ions for a few years after LS3
- physics program – factor > 100 increase in statistics
  - (today maximum readout ALICE ~ 500 Hz)
- for triggered probes increase in statistics by factor > 10
- ALICE upgrade Letter Of Intent submitted to LHCC

Conclusions

- A rich program on Pb–Pb, proton-Pb and proton proton in Run 2.

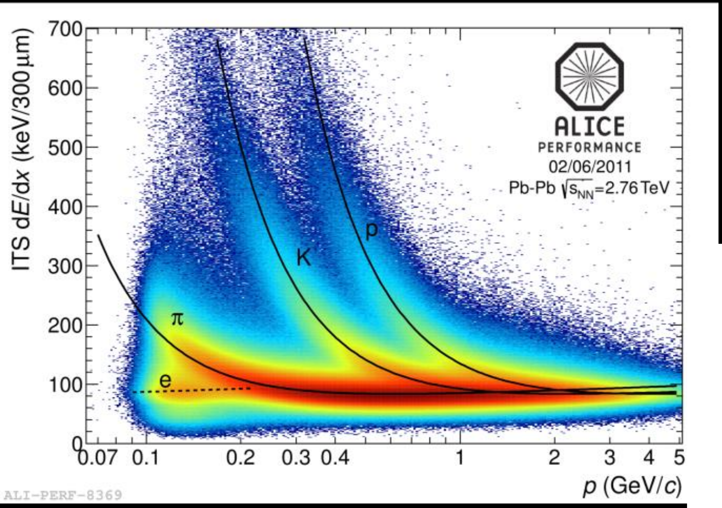
- Low p_T , photon induced and diffractive physics obtains now a boost with the installation of a new detector that enhances the potential of ALICE.

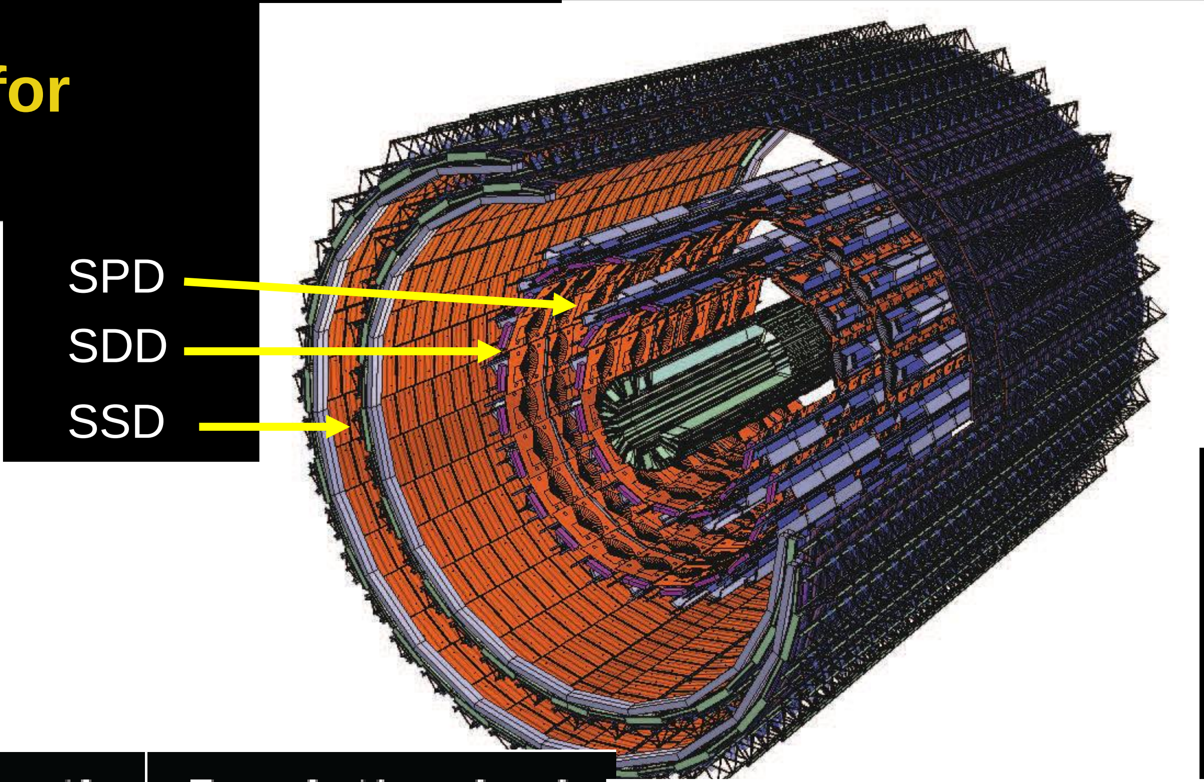
  AD forward detectors are now taking data. We are in the process of evaluating the performance (efficiency, purity for selecting Diffractive events but also as a general trigger system for ALICE)

- Cosmic Ray Physics with ALICE
  by A. Fernandez today 17:20
- Heavy ions physics at ALICE CMS and ATLAS
  by B. Wyslouch tomorrow 4-August
- Photon and neutral pion production in pp and PbPb collisions at the LHC energies in ALICE.
  by Podist Kurashvili 5-August
- Transverse polarization measurement of Lambda particles with ALICE at the LHC
- By Liliet Calero 8-August

Backup

all known techniques for particle identification:





Layer	Det. Type	Radius (cm)	Length (cm)	Resolution (µm)	
				rφ	z
1	pixel	3.9	28.2	12	100
2	pixel	7.6	28.2	12	100
3	drift	15.0	44.4	35	25
4	drift	23.9	59.4	35	25
5	strip	38.0	86.2	20	830
6	strip	43.0	97.8	20	830

Inner Tracking System

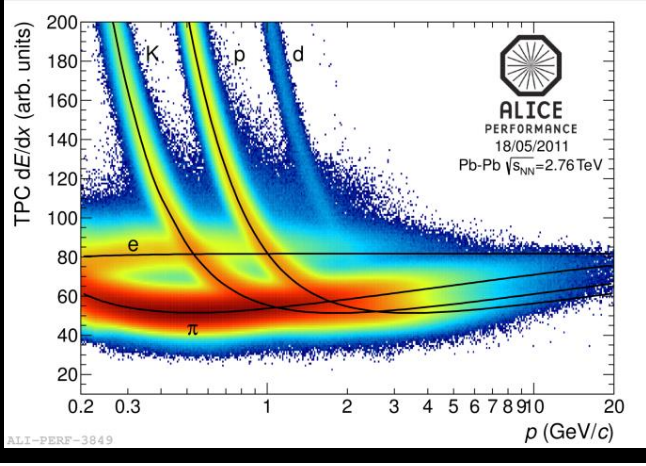
3 silicon technologies

low momentum acceptance

high granularity

low material budget

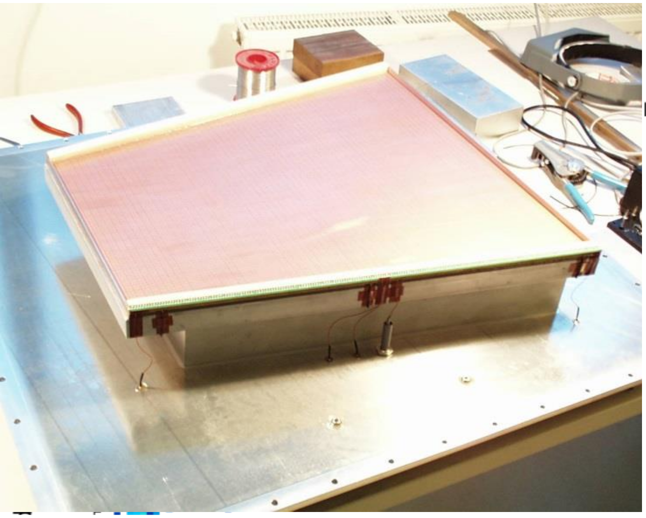
all known techniques for particle identification:

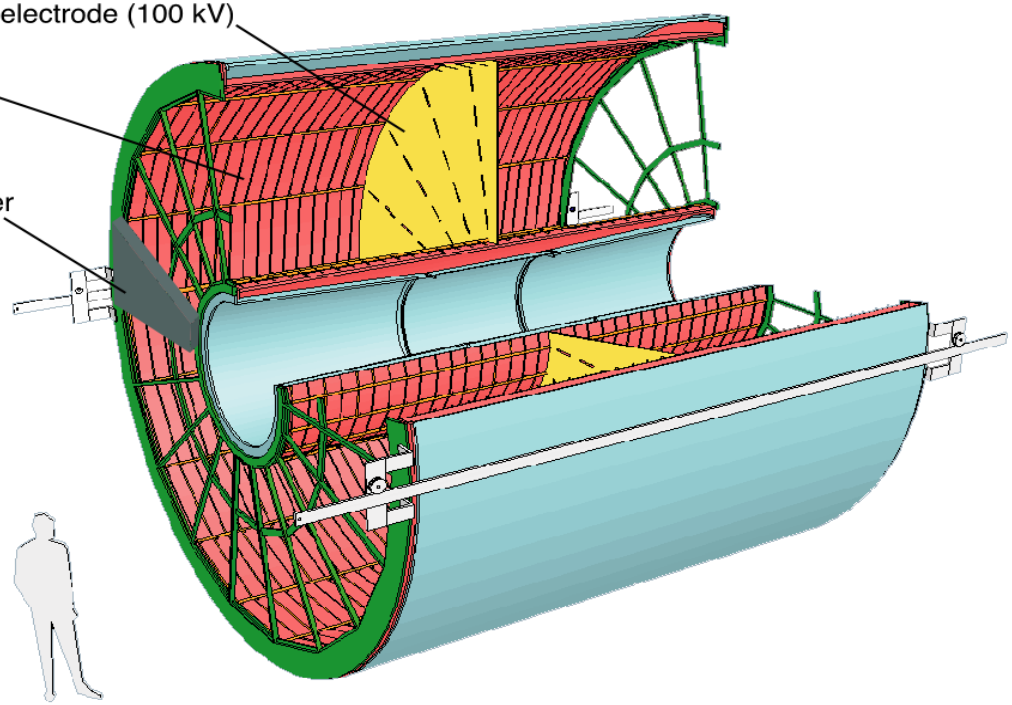


drift gas
90% Ne - 10%CO_2

for tracking and PID via dE/dx

$-0.9 < \eta < 0.9$





Time Projection Chamber
largest ever: 88 m^3, 570 k channels

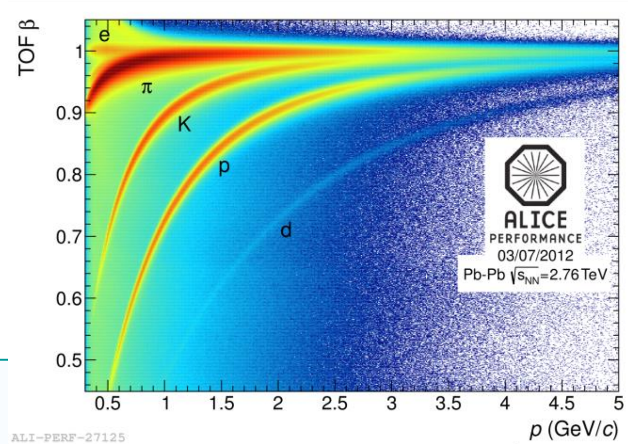
all known techniques for particle identification:

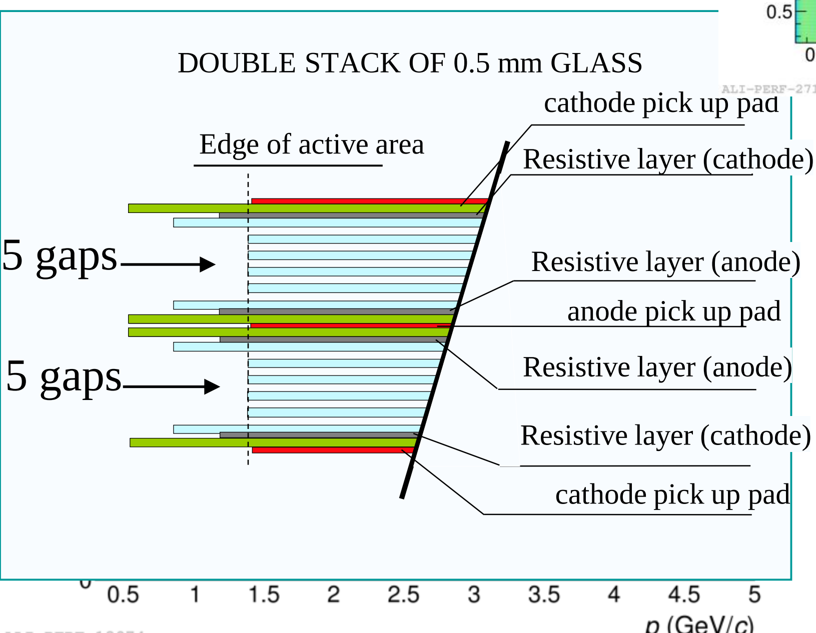
Time Of Flight

Multigap Resistive Plate Chambers

for π, K, p PID
π, K for *p* <2 GeV/c
p for *p* <4 GeV/c

- 0.9 < η < 0.9
full ϕ





all known techniques for particle identification:

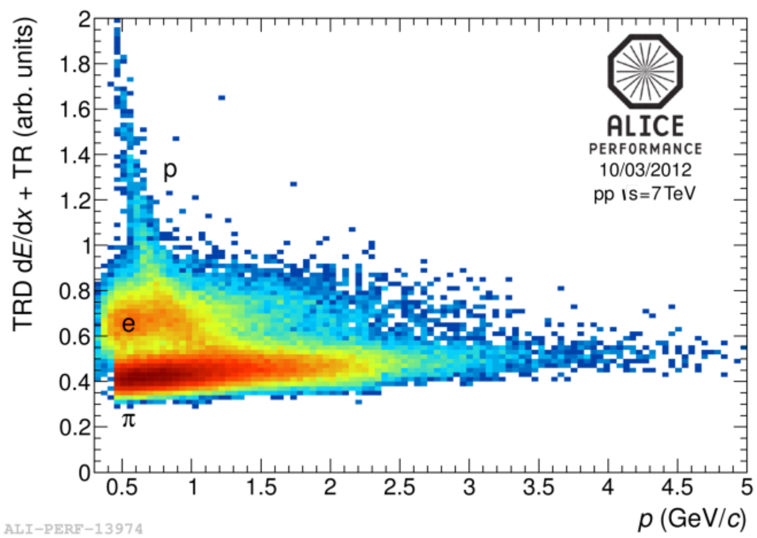
$-0.9 < \eta < 0.9$

Transition Radiation Detector

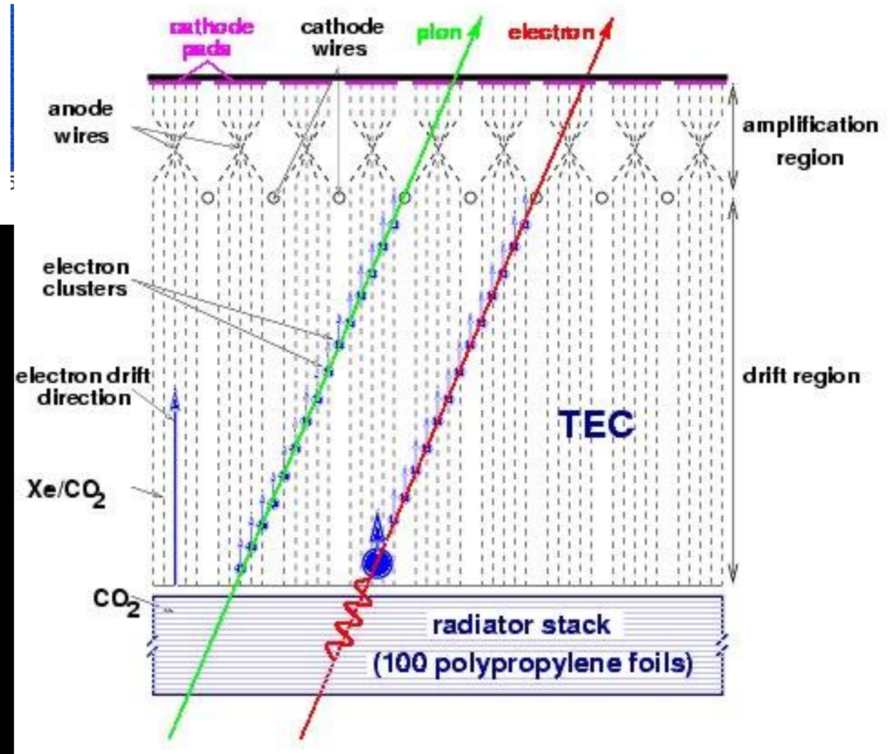
for e PID, *p*>1 GeV/c for e and high p_t trigger, *p*>3 GeV/c

Large (800 m^2), high granularity (> 1M ch.)

fiber radiator to induce TR (γ > 2000)

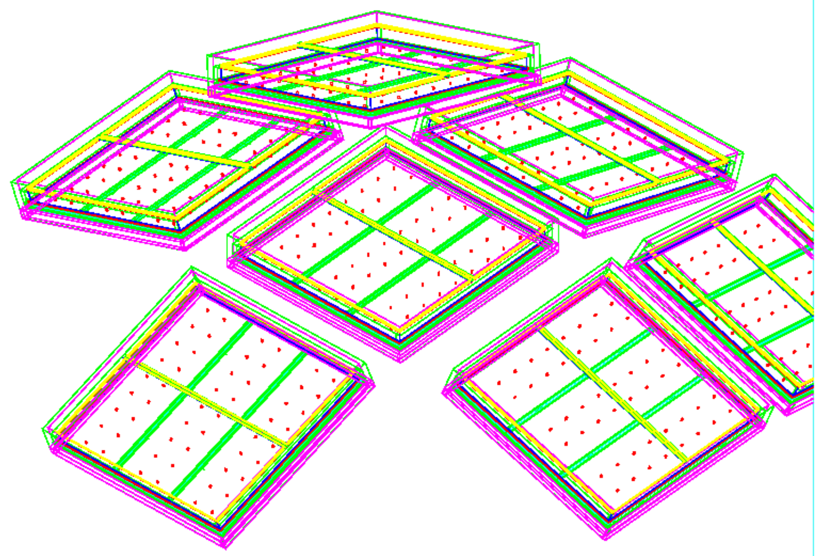


TRD

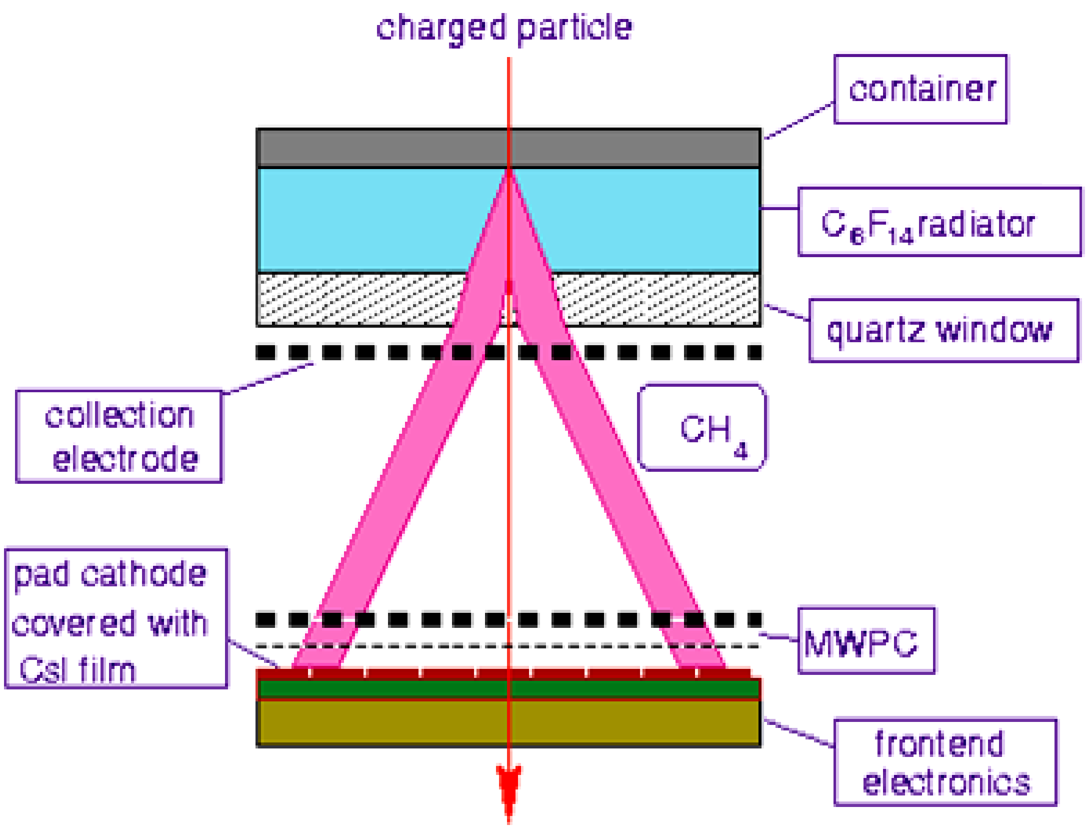


all known techniques for particle identification:

7 modules, each ~1.5 x 1.5 m^2



High Momentum Particle Identification



RICH

HMPID