NA45/CERES at the SPS

(tips and tricks around the experiment)

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CERES Collaboration

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CERES run history

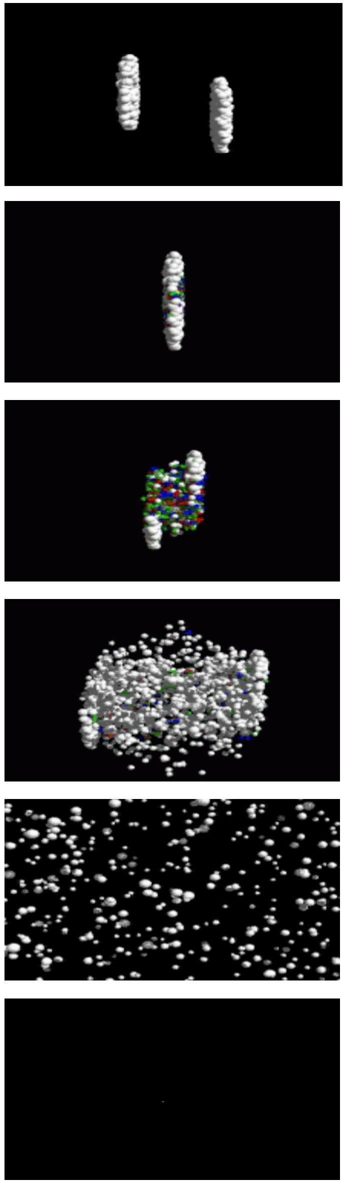
1990	installation	
1991	completed	
1992	200 GeV S+Au	4M central 445 open pairs
1993	450 GeV p+Be 450 GeV p+Au	10M pairs 3M pairs
1995	160 GeV Pb+Au	10M central
1996	160 GeV Pb+Au	50M central 2700 open pairs
1997	upgrade	
1998	upgrade	
1999	40 GeV Pb+Au	10M central 185 open pairs
2000	80 GeV Pb+Au 160 GeV Pb+Au	1M central 30M central

this talk

- 1990-1996 **prehistory**
- 1997-1998 **upgrade**
- 1999-2000 **running**
- 2000-2005 **calibration**
- 2001-2007 **analysis**

Sources of e^+e^- pairs

UrQMD 160 GeV Au+Au



all stages contribute

Drell-Yan

thermal radiation from QGP (quark annihilation)

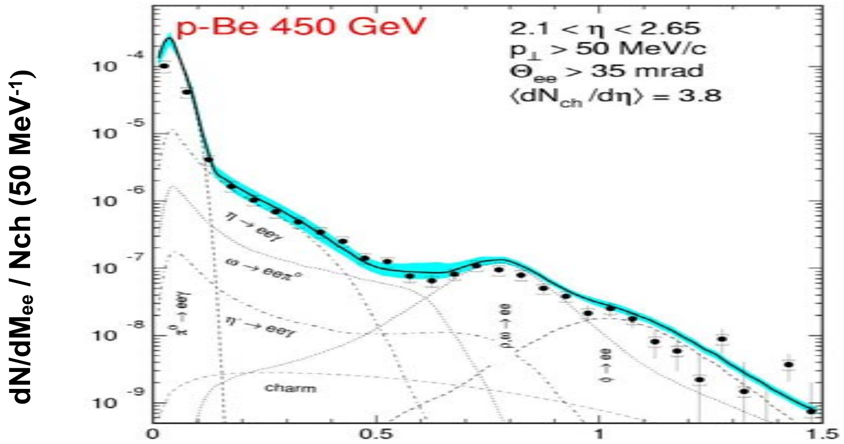
thermal radiation from hadron gas (pion annihilation)

meson decays

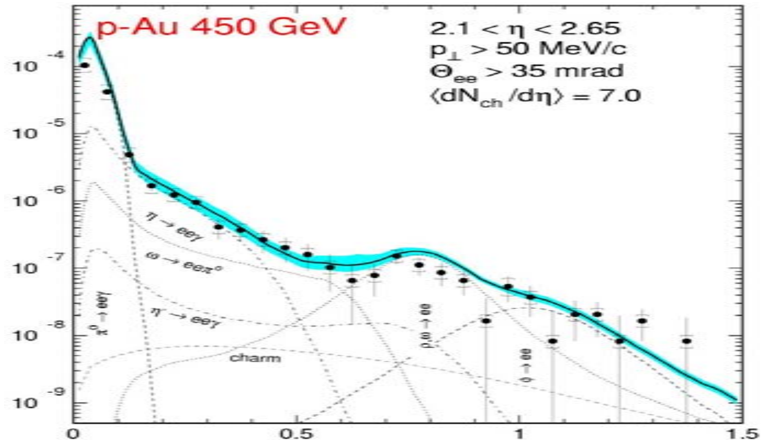
gamma conversion

CERES results 92-96

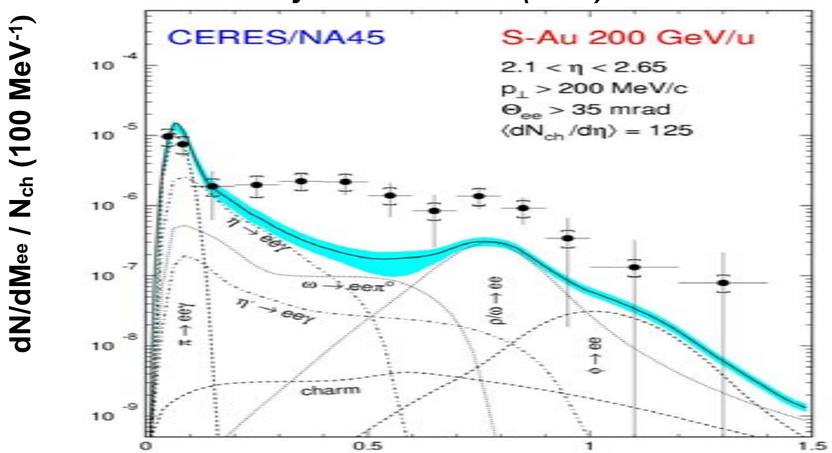
Eur. Phys. J C4 (1998) 231



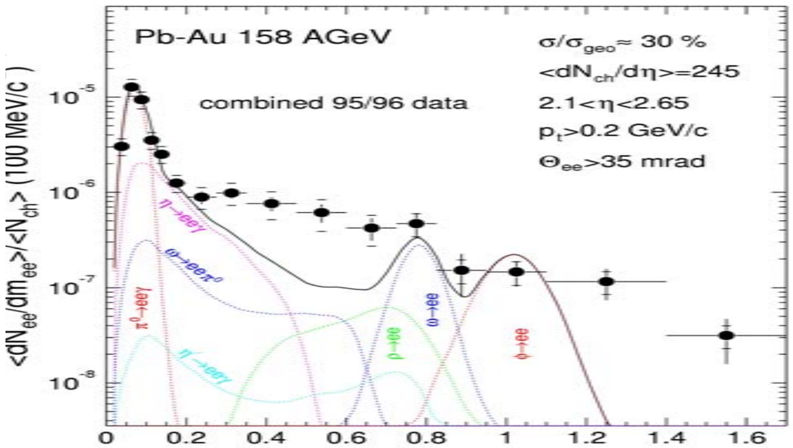
Eur. Phys. J C4 (1998) 231



Phys. Rev. Lett. 75 (1995) 1272



Eur. Phys. J. C41 (2005) 475



→ excess of e^+e^- pairs in heavy ion collisions

Origin of the excess pairs

- ***absent in p+A, present in A+A***
- ***M_{ee} range 0.2-1.0 GeV/c^2***
- ***low pt***
- ***proportional to charged-particle-multiplicity squared***

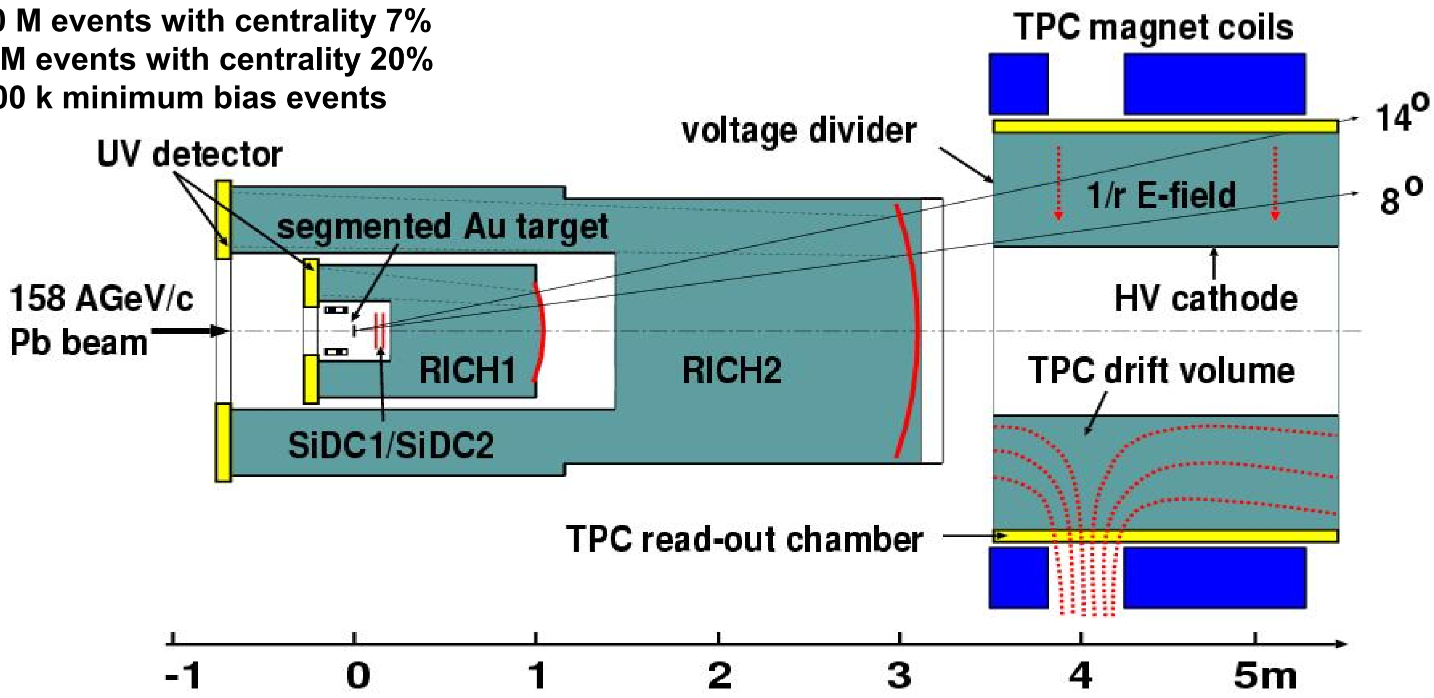
consistent with

$$\pi + \pi \rightarrow \rho \rightarrow e^+ e^-$$

$$q + qbar \rightarrow \gamma^* \rightarrow e^+ e^-$$

setup with TPC: 1999 and 2000

run 2000: 30 M events with centrality 7%
2 M events with centrality 20%
500 k minimum bias events



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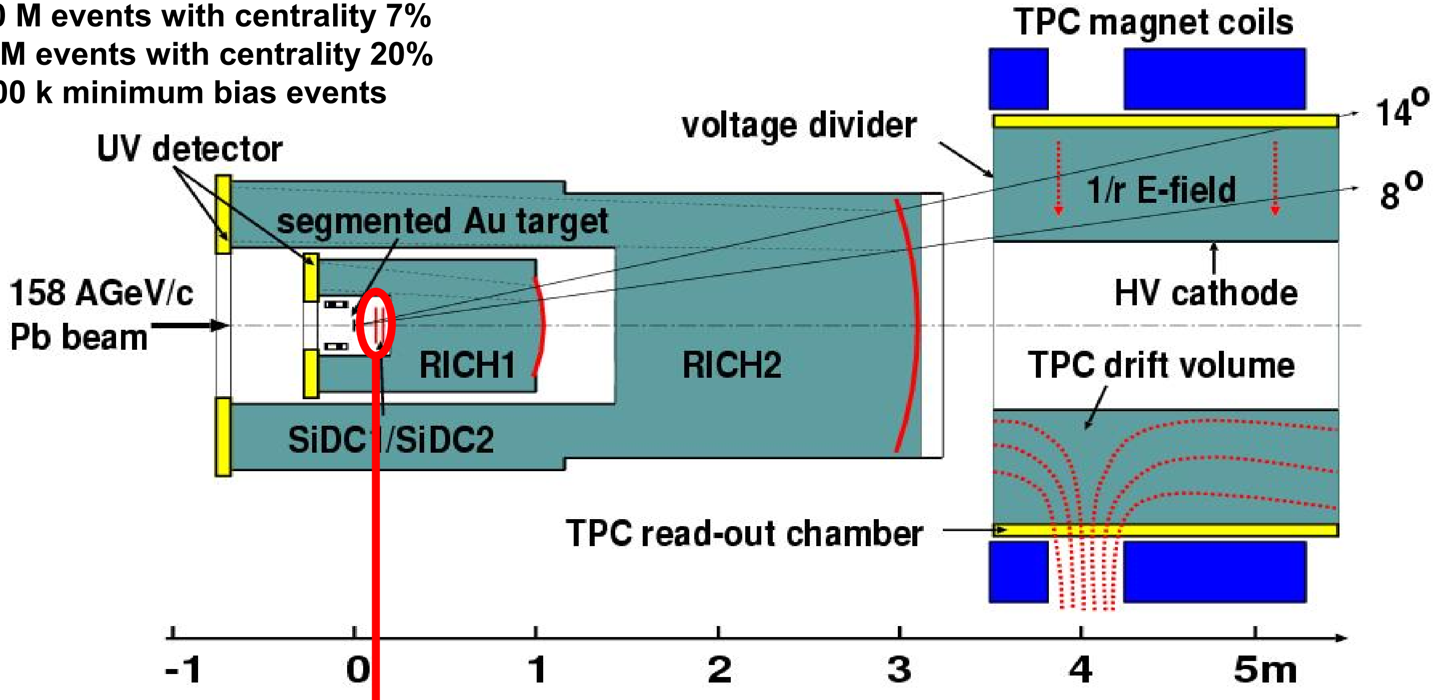
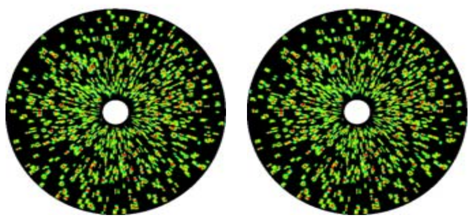
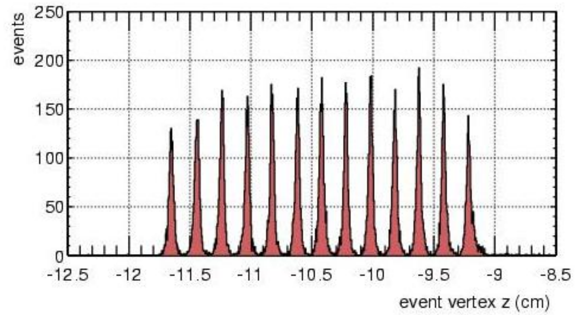


SD: event vertex, track vertex and angle





event Δz = 0.2 mm
track $\Delta\theta$ = 0.2 mrad
$\Delta\varphi$ = 2 mrad

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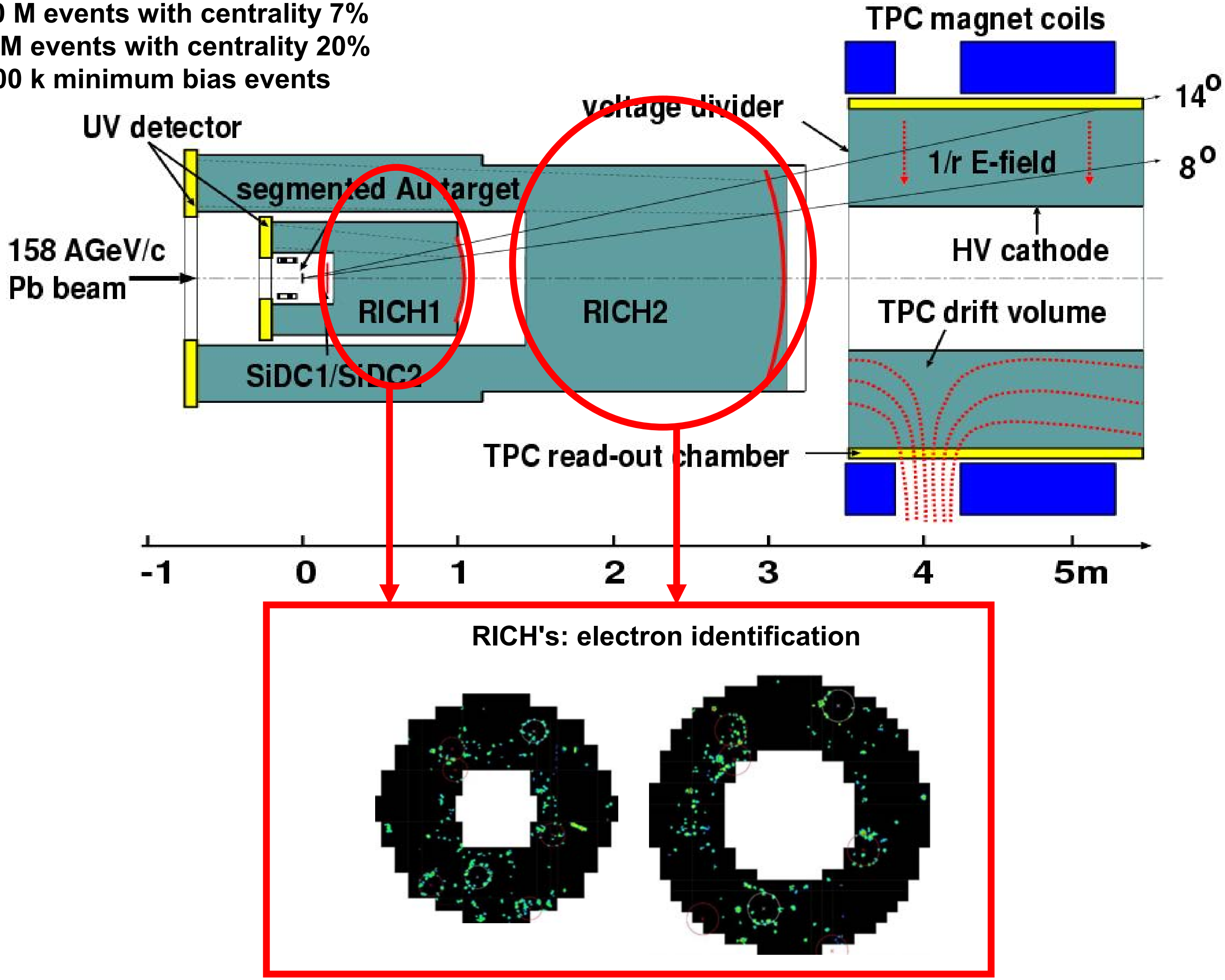

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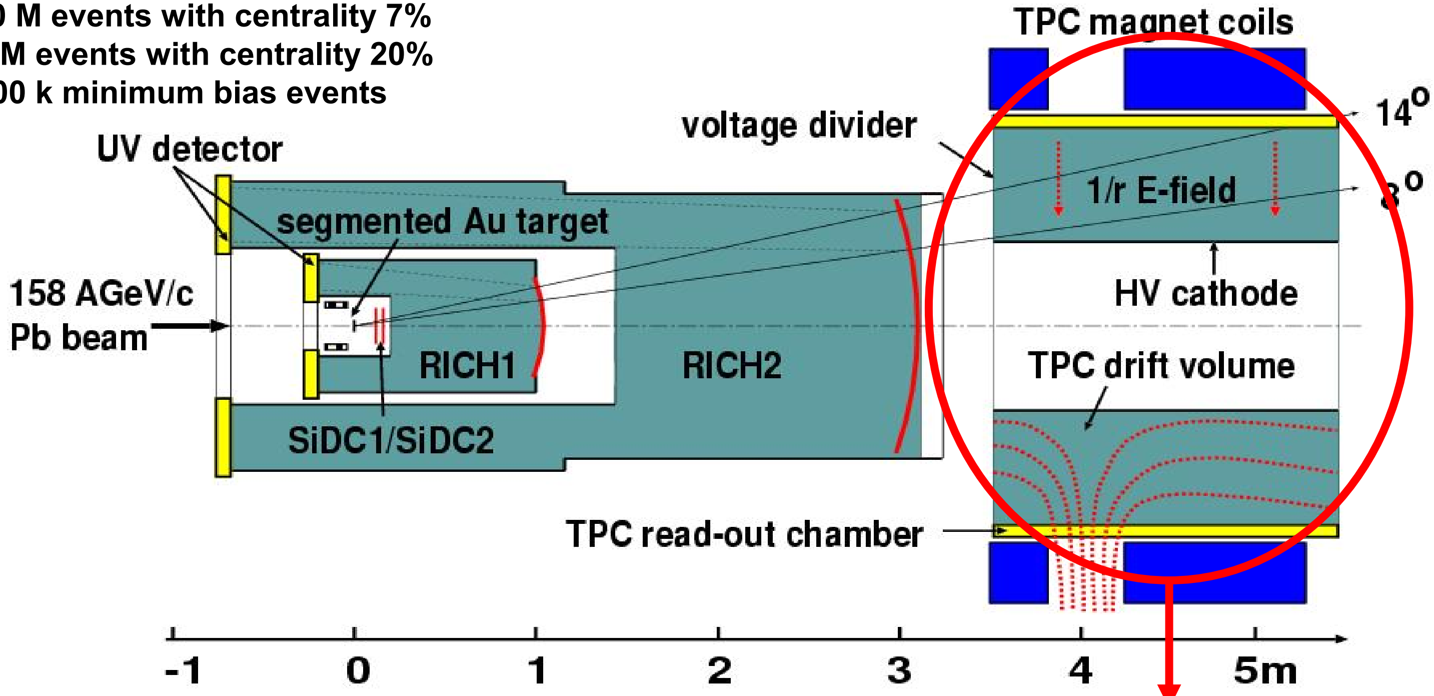
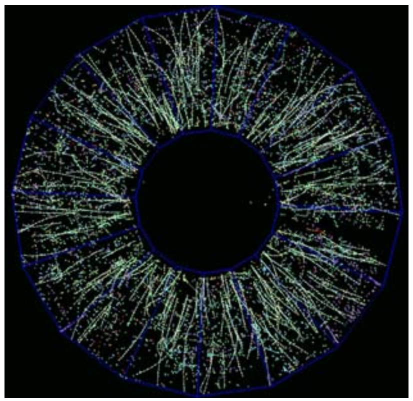


radial drift TPC: momentum and energy loss

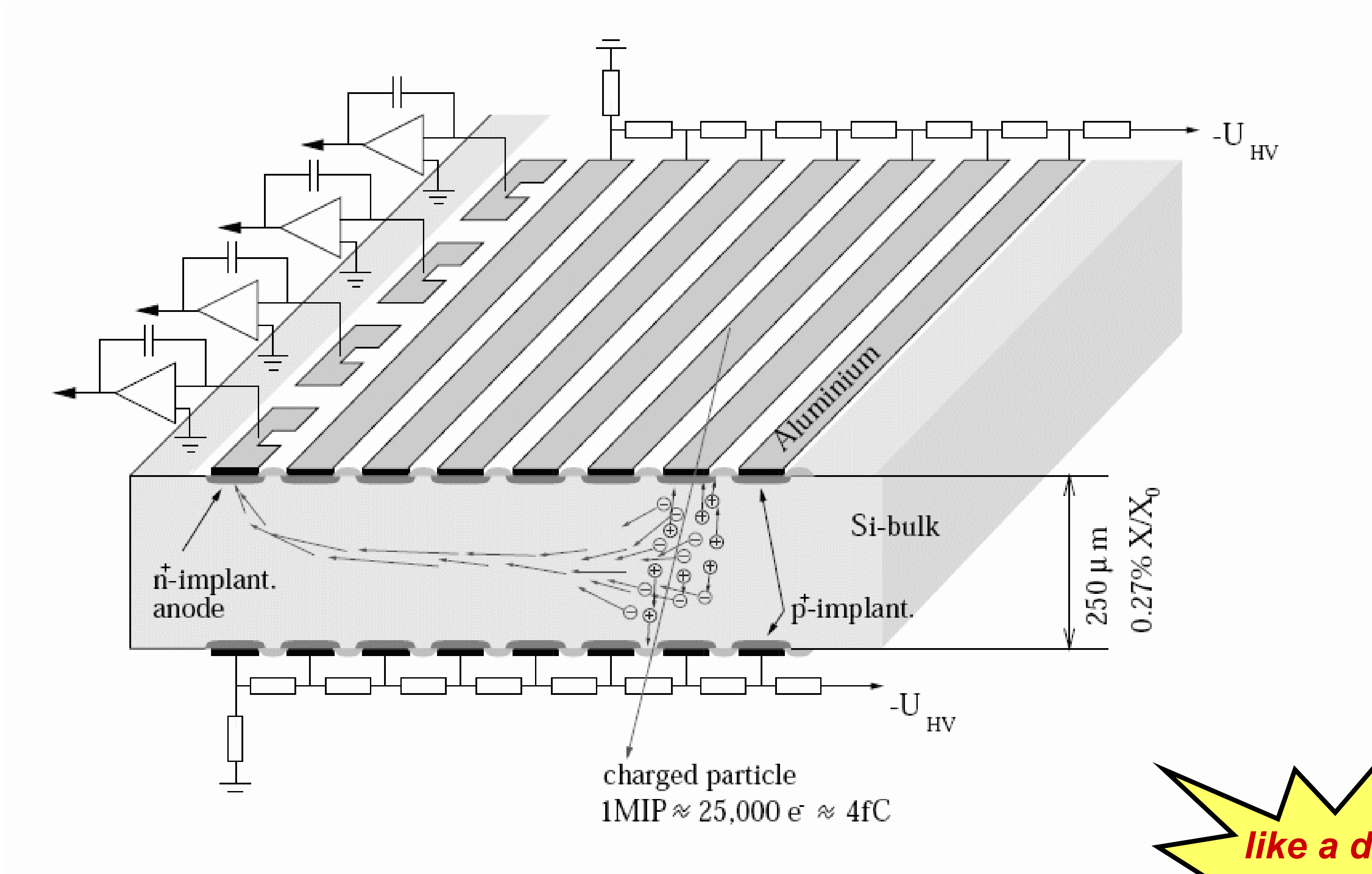


$\Delta p/p = 2\% \oplus 1\% * p/GeV$

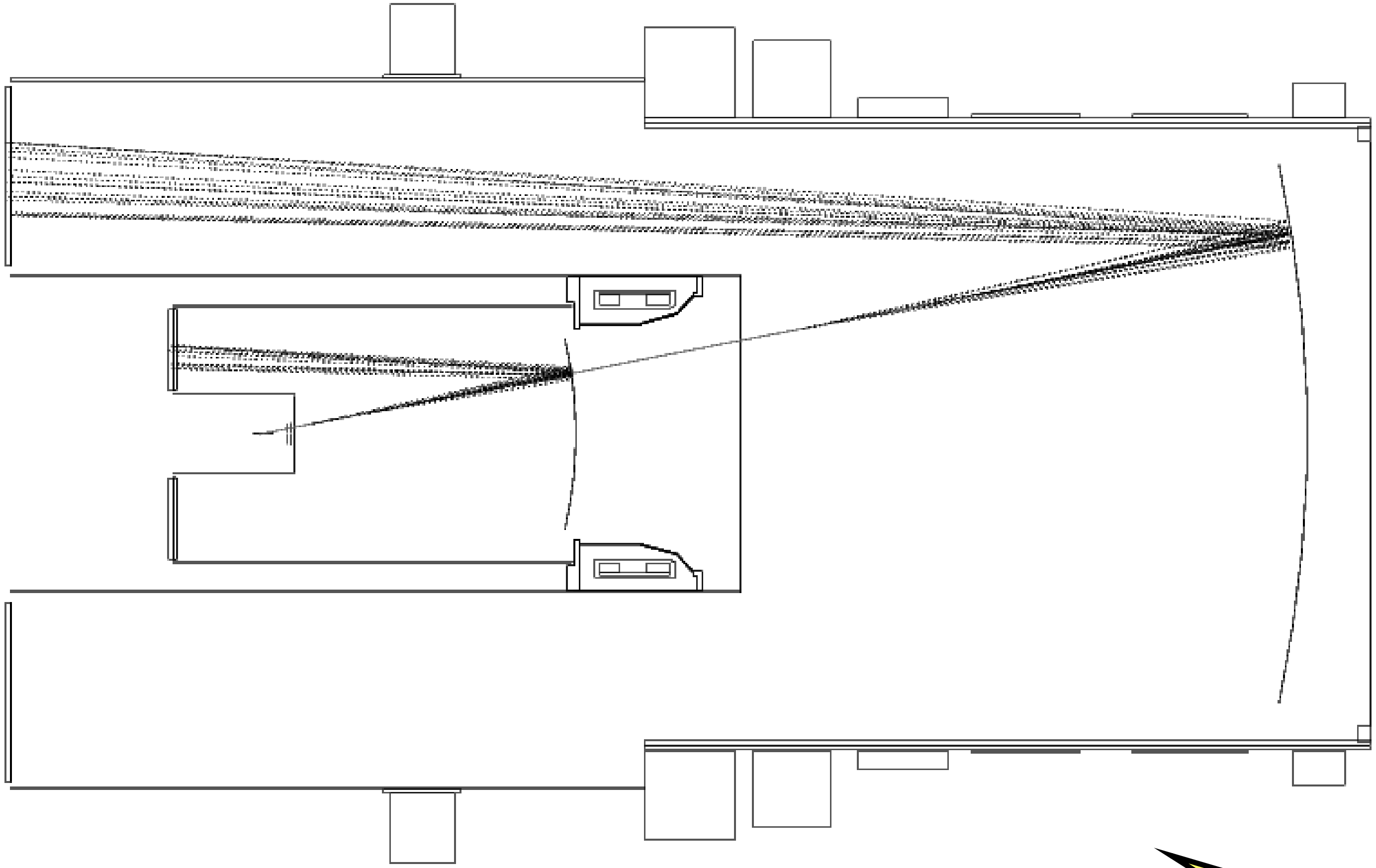
$\Delta m/m$ = 3.8 % for ϕ

$\Delta(dE/dx)/(dE/dx)$ = 10%

Silicon Drift Detectors (SDD)



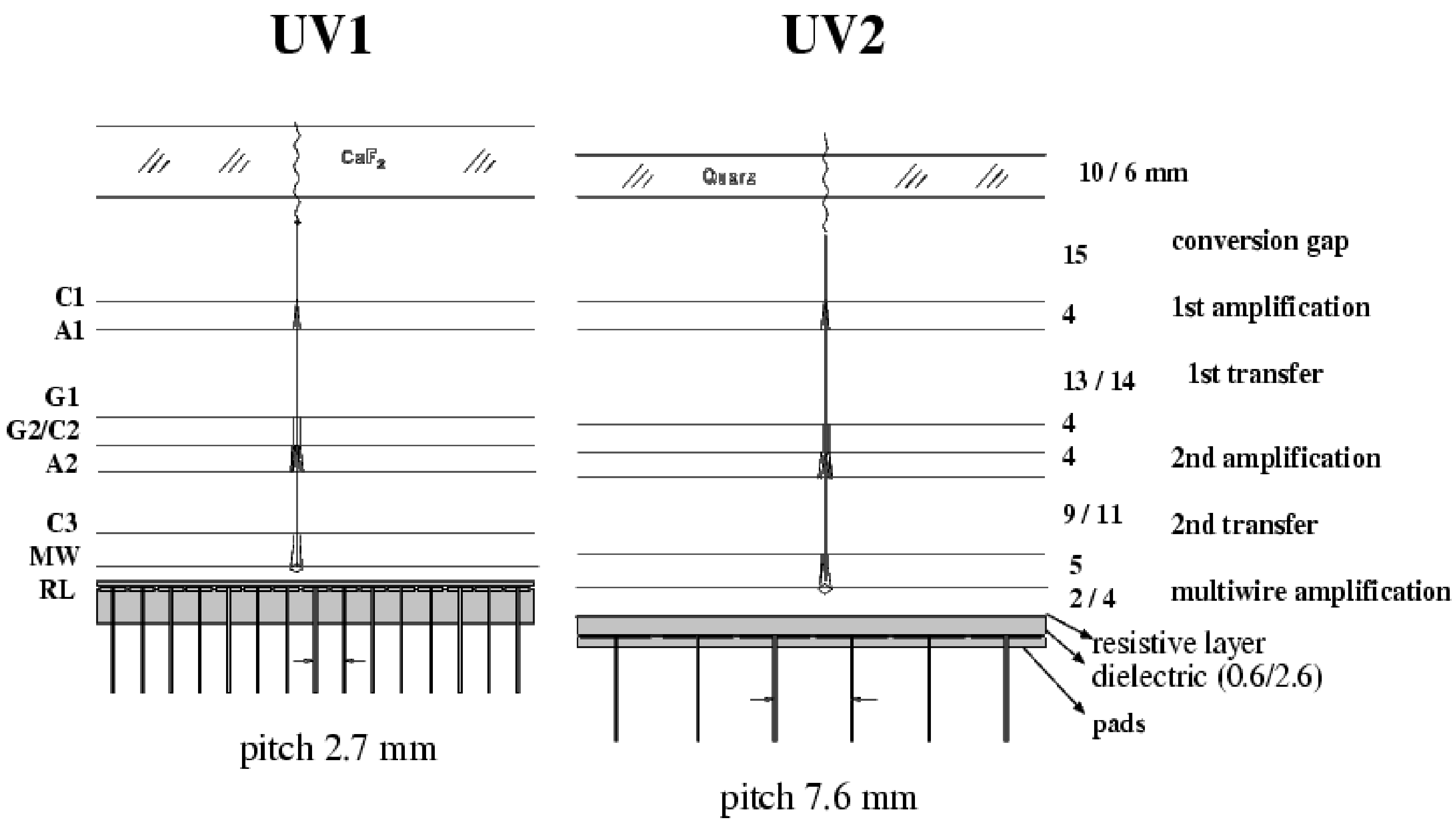
Ring Imaging Cherenkov (RICH)



Ring Imaging Cherenkov (RICH)

	RICH1	RICH2
RICH specifications:		
$\Delta\eta$	0.93	0.61
$< \eta >$	2.34	2.34
Radiator length (m)	0.9	1.75
Radiator gas	CH_4	CH_4
γ_{thr} (measured)	31.4	32.6
window	CaF_2	quartz
RICH band width (eV)	5.4 – 8.5	5.4 – 7.4
Mirror specifications		
material (thickness)	carbon fiber (0.8 mm)	glass (6 mm)
geometry	one piece	10 azimuthal segments
inner/outer diameter (m)	0.20 – 0.65	0.85 – 1.75
focal length (cm)	126	420
UV-detector specifications:		
UV-detector area (m^2)	0.42	2.84
inner/outer diameter (m)	0.27 – 0.79	1.06 – 2.20
number of pads	53800	48400
pad size (mm^2)	2.74×2.74	7.62×7.62
channels/module	8×32	11×11
number of modules	210	400
readout chains	16	14
readout freq. (MHz)	2.5	2.5
readout time (μs)	1600	1600

Ring Imaging Cherenkov (RICH)

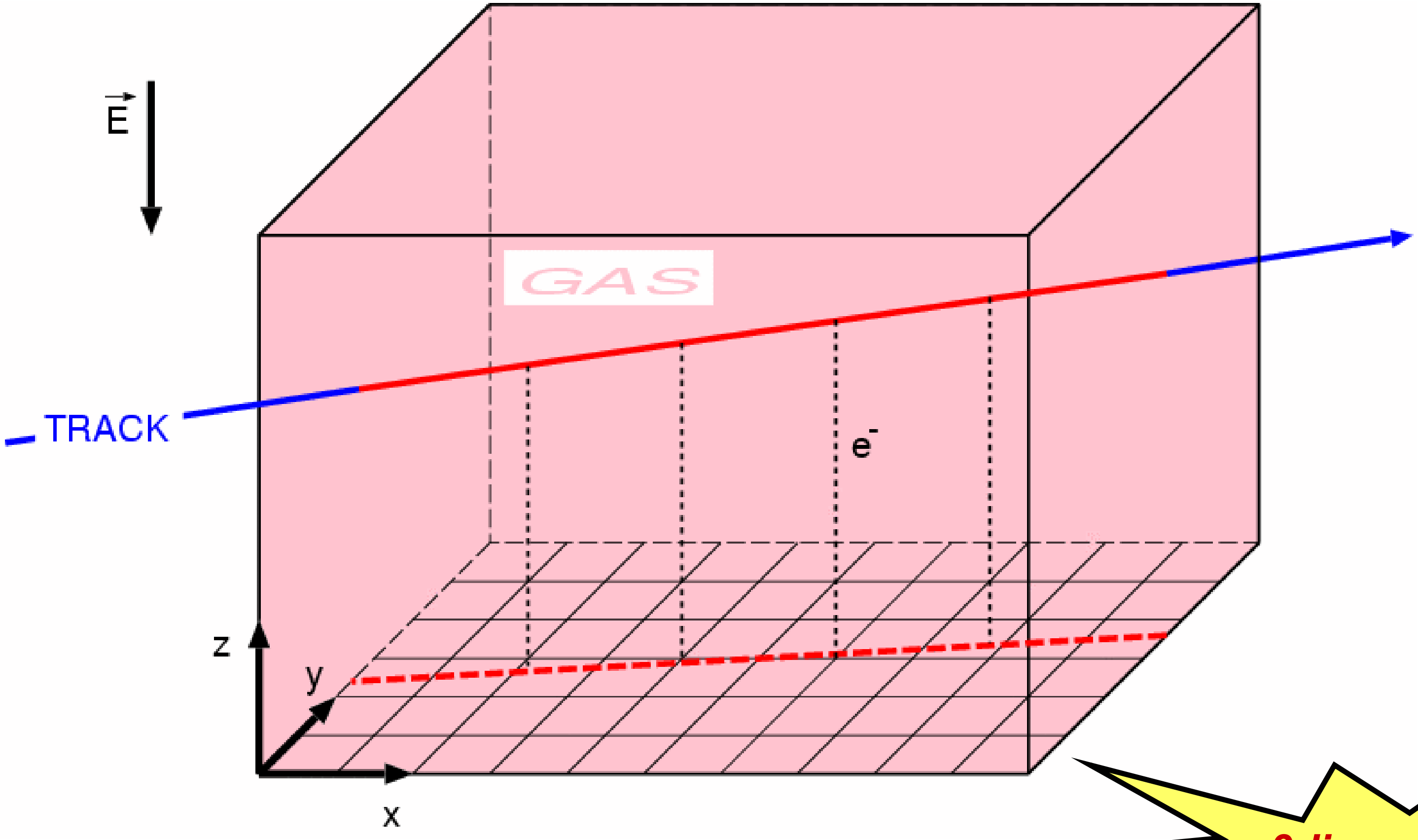


Ring Imaging Cherenkov (RICH)

If I were a RICH man
Ya ha diddle diddle...

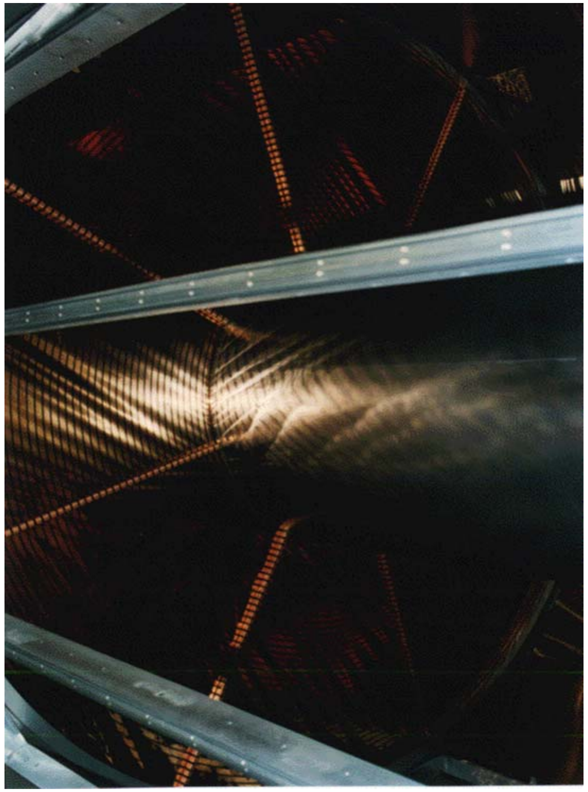
Ring Imaging Cherenkov (RICH)

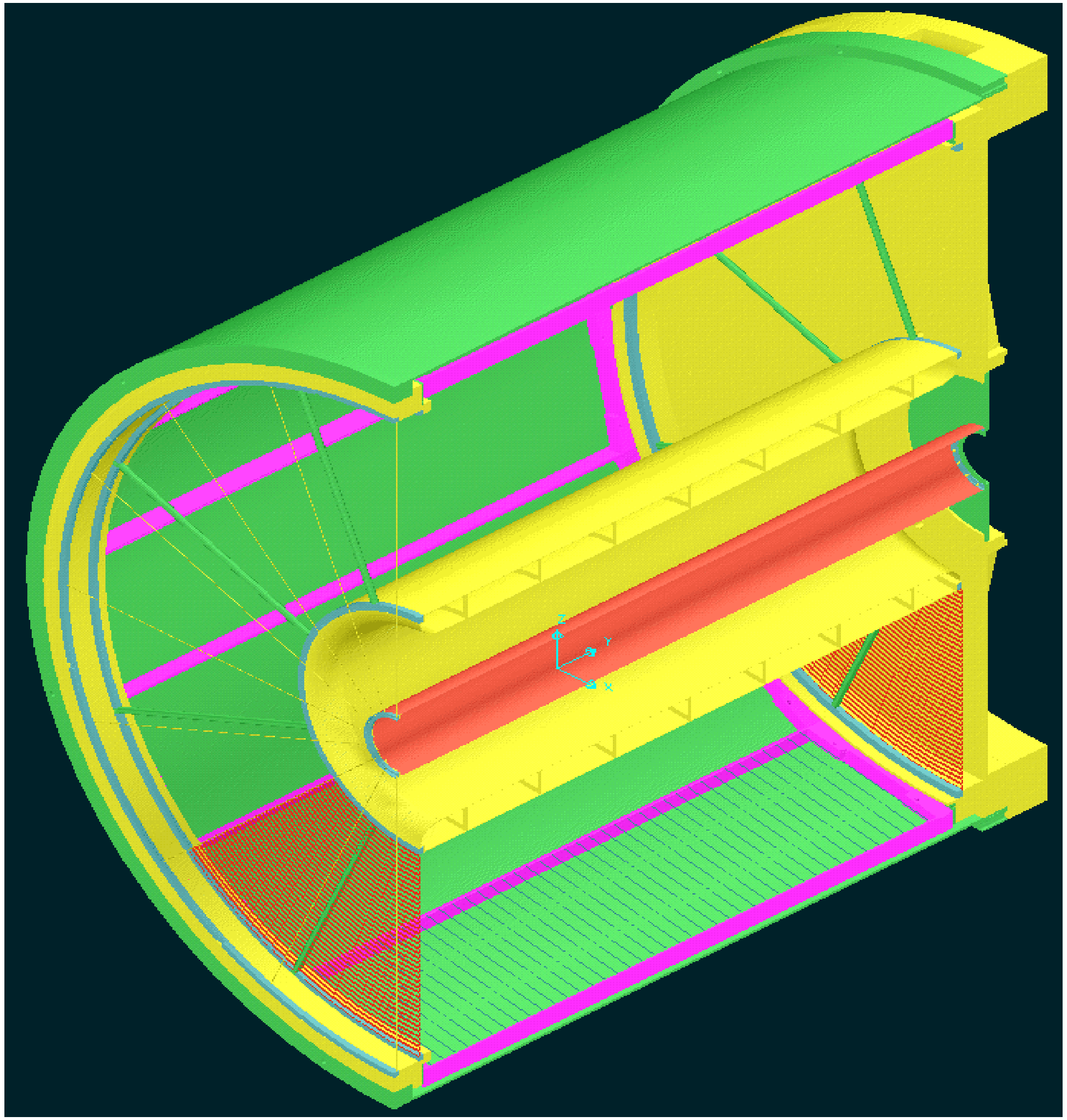
TPC – principle of operation



3dim position information

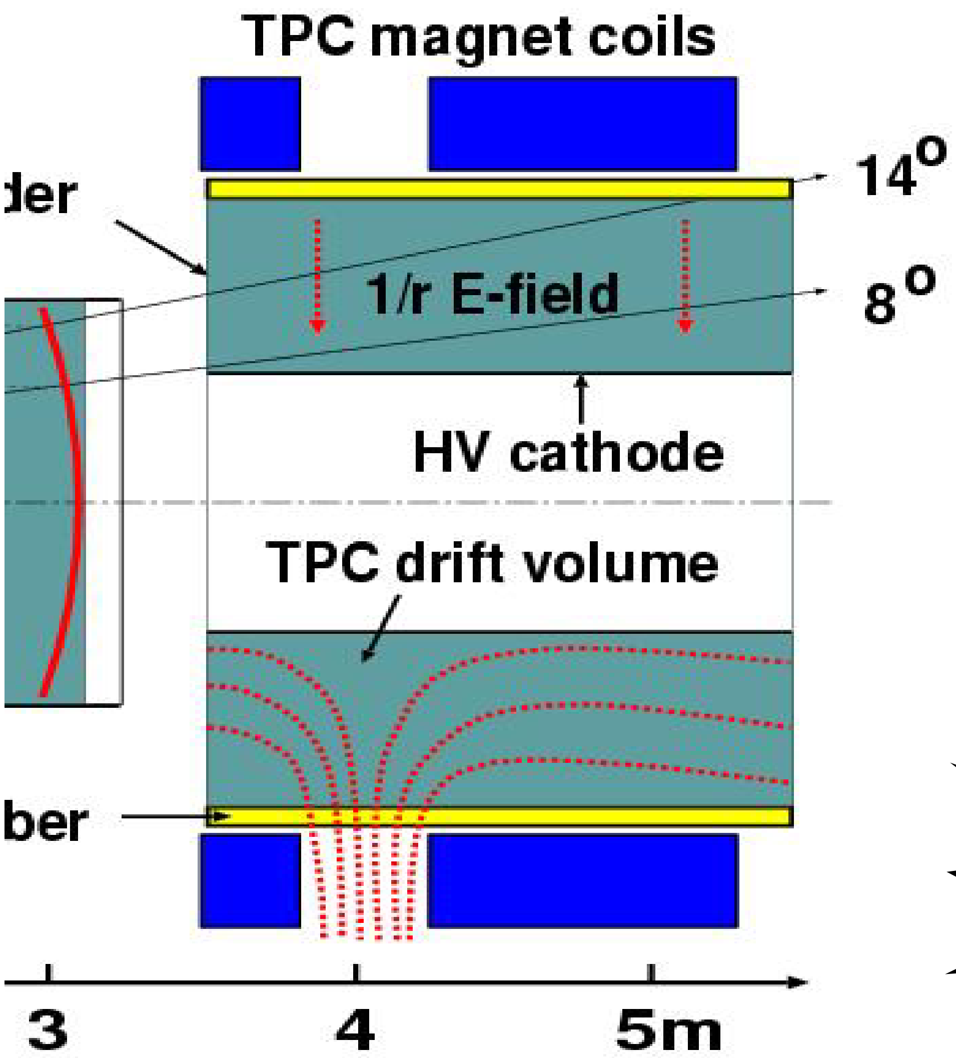
CERES TPC

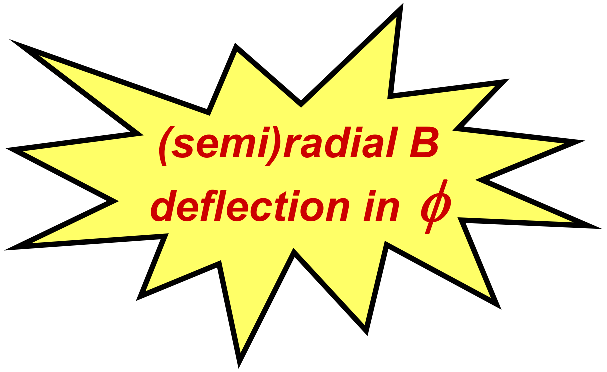


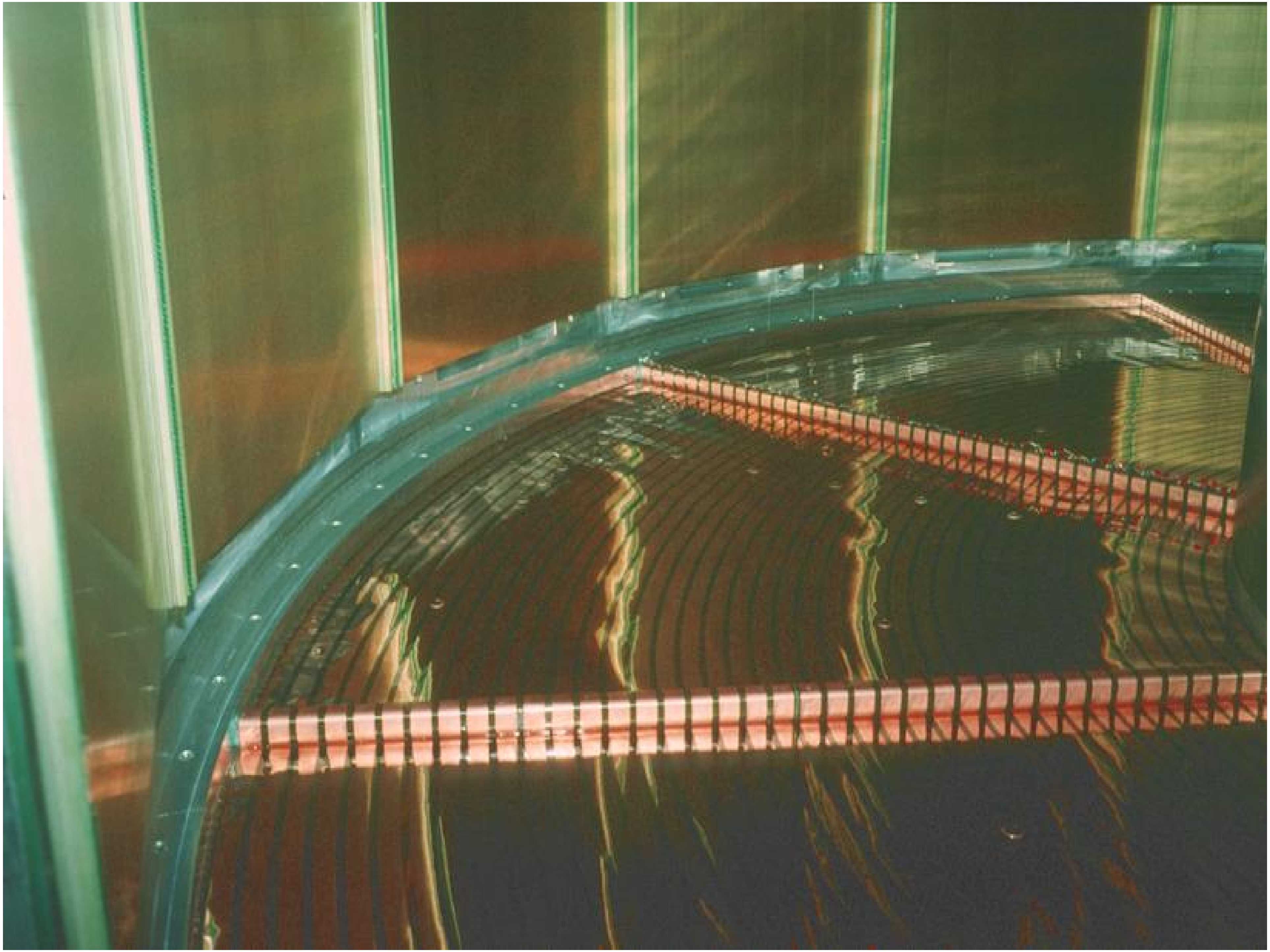


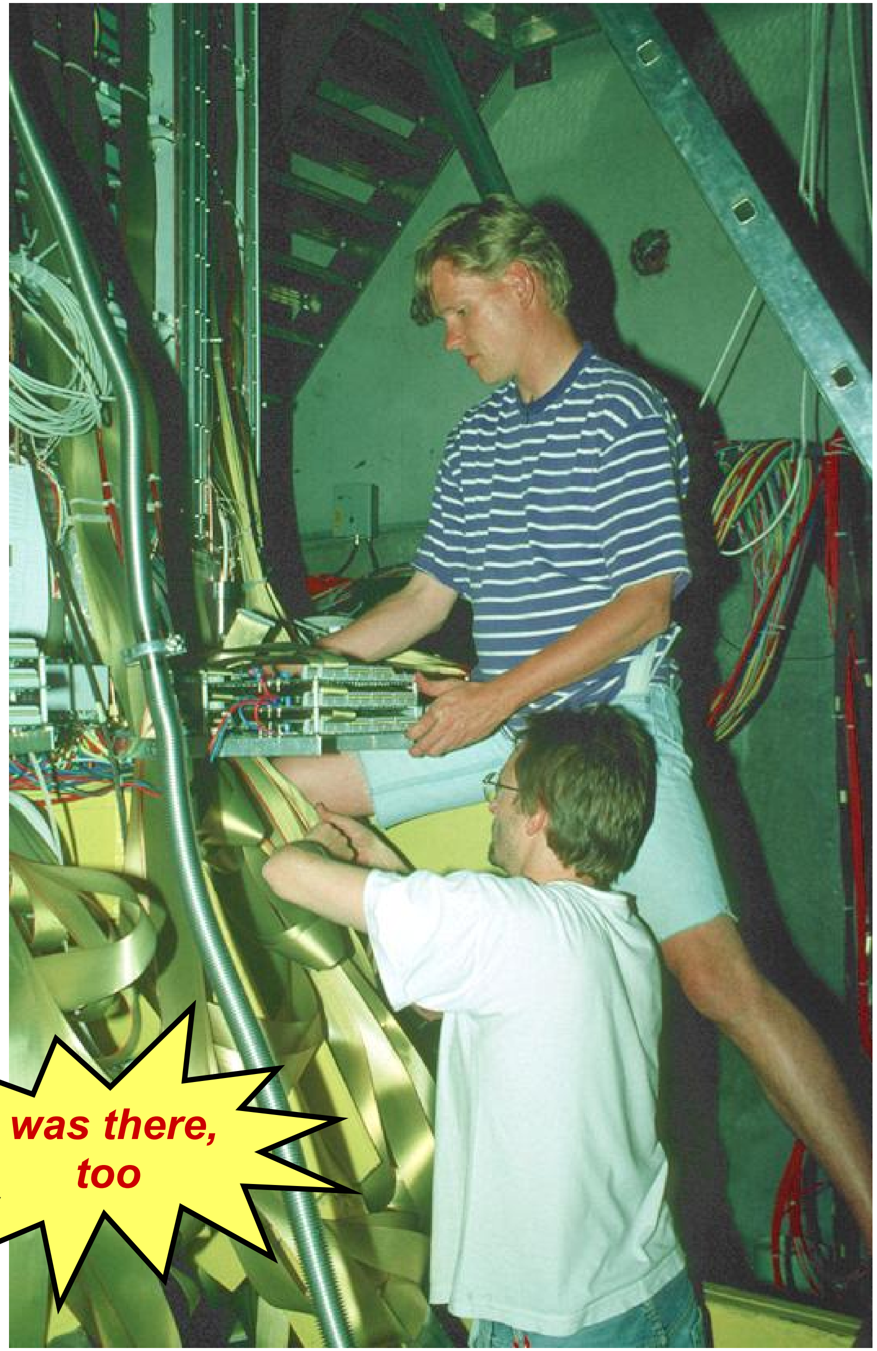
- cylinder Φ 2.6 m x 2 m
- gas Ne:CO_2 (80:20)
- radial E-field E_R~1/r with E=200-600 V/cm
- radial drift with v=0.7-2.4 cm/μs

TPC E and B fields



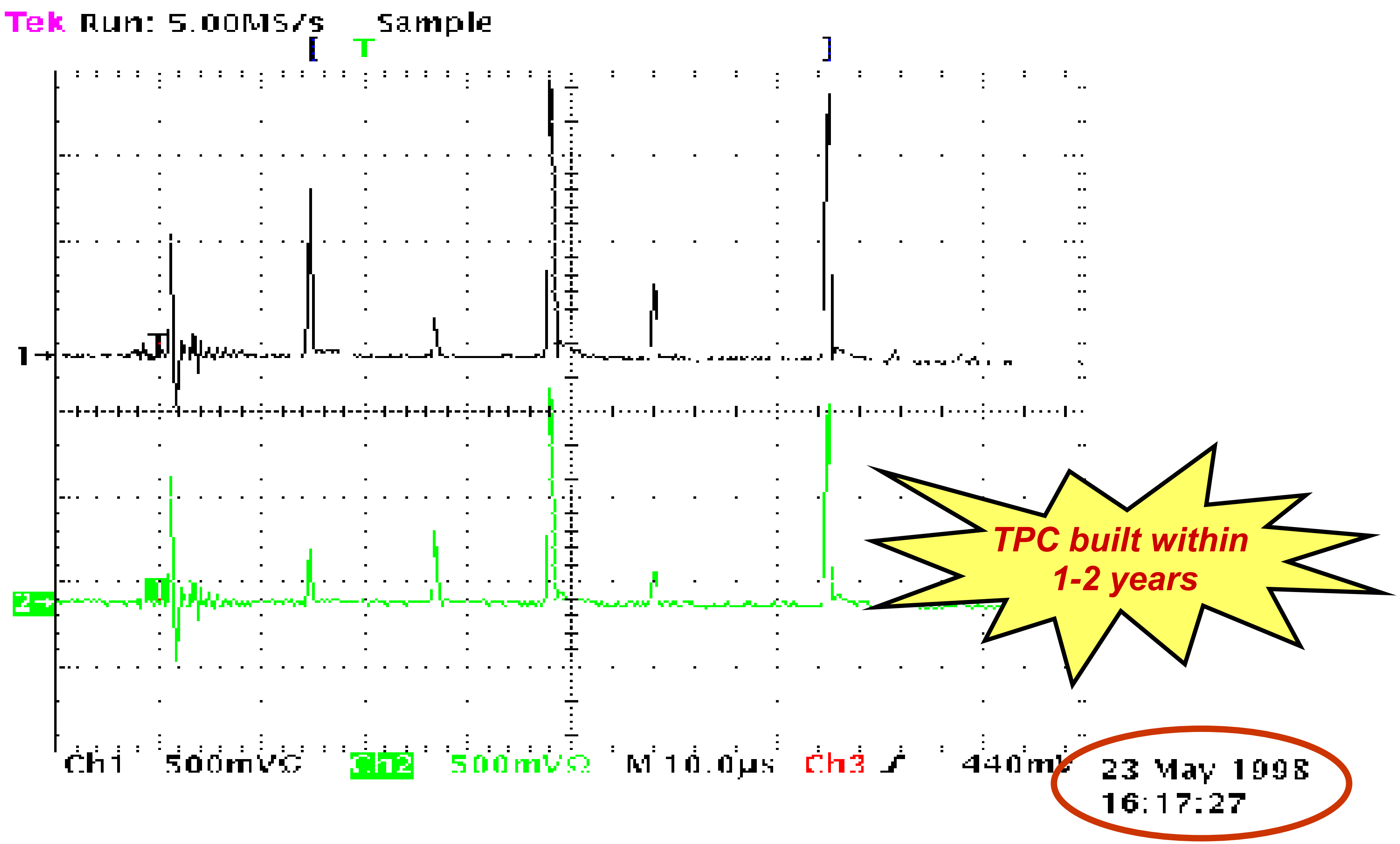




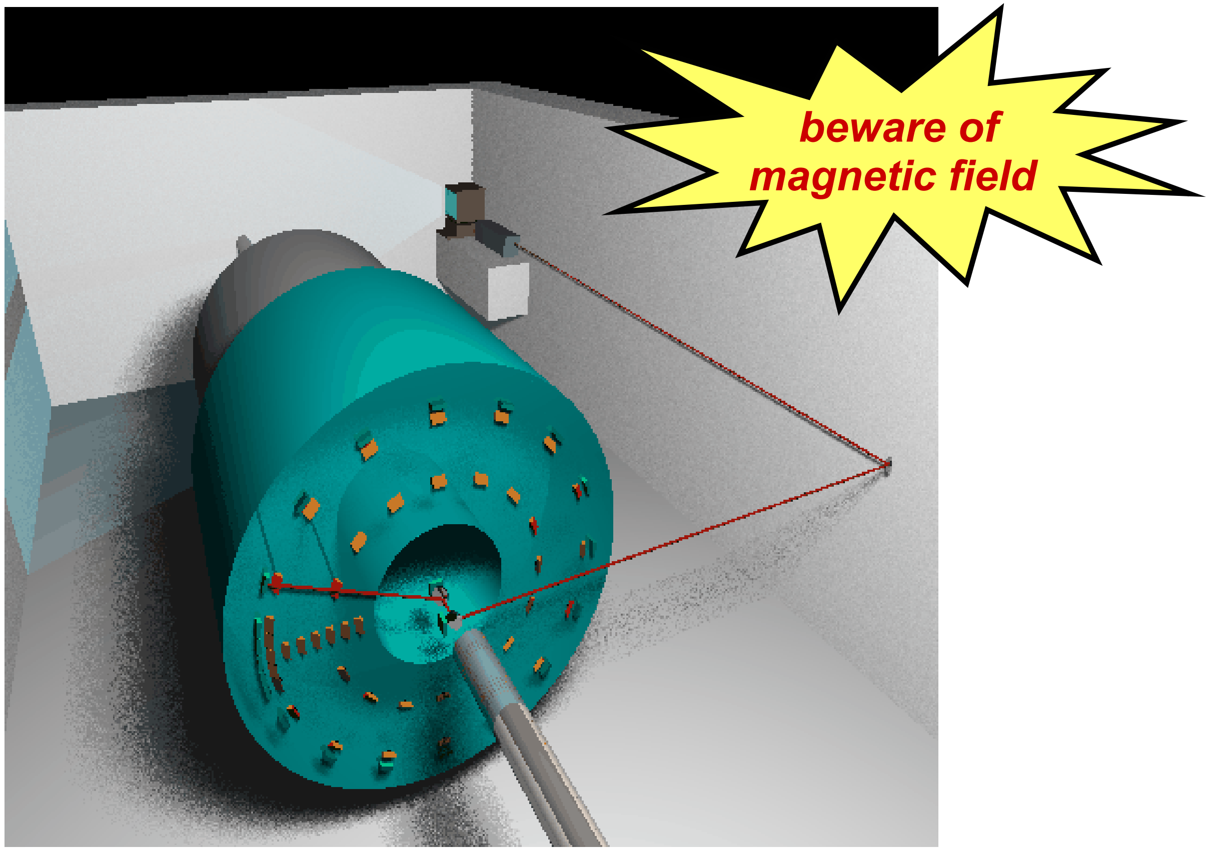


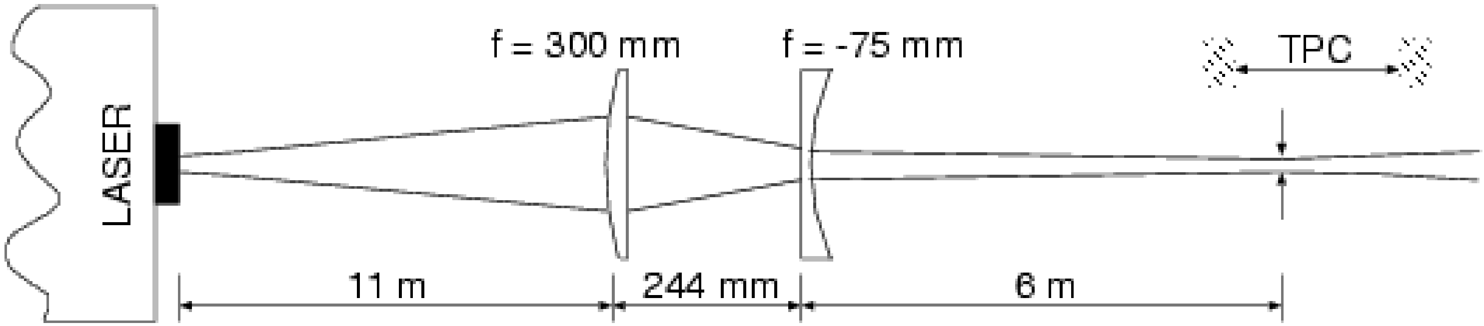
I was there, too

first laser shot into CERES TPC



laser for TPC calibration





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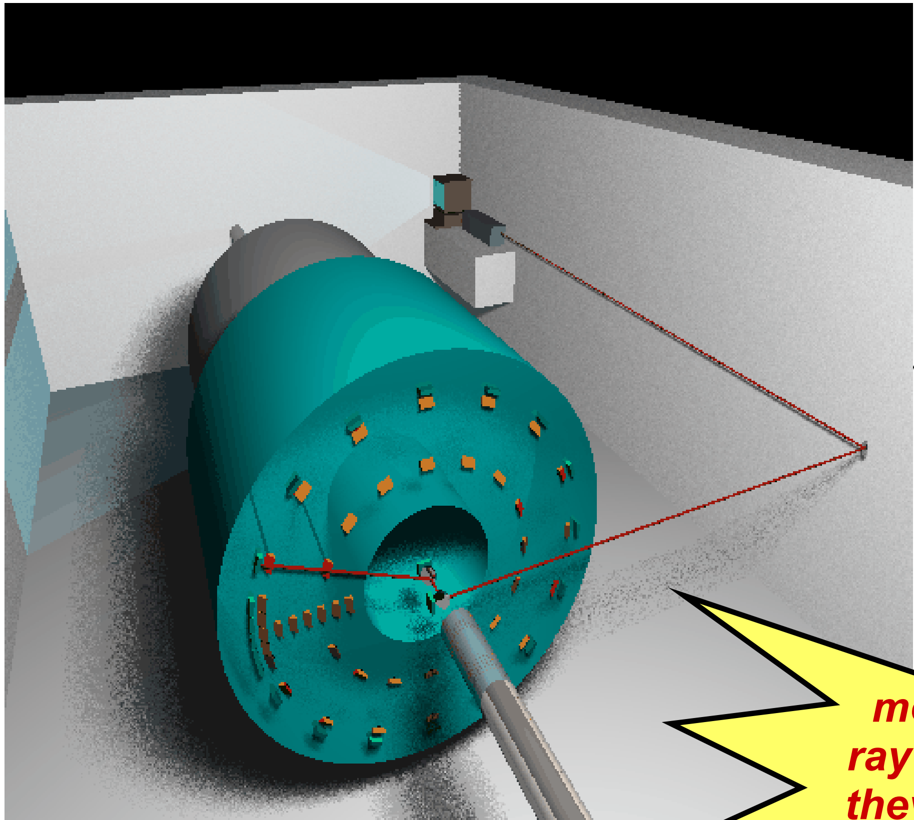
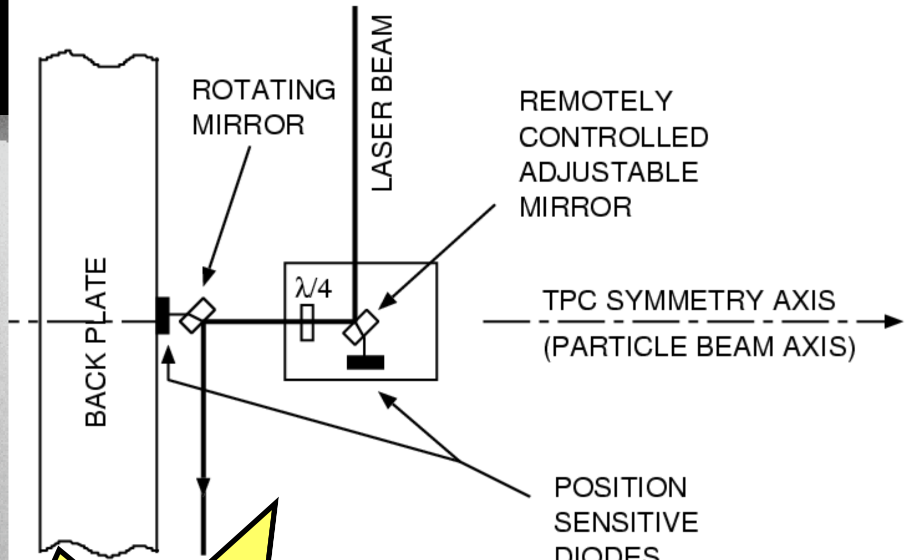
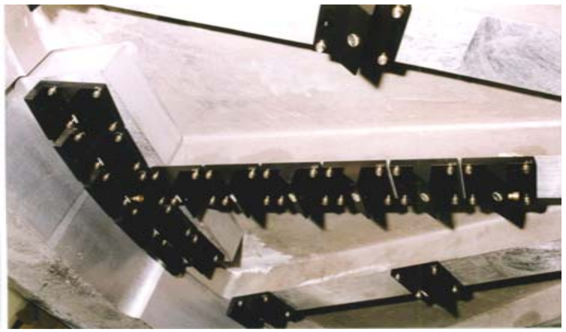
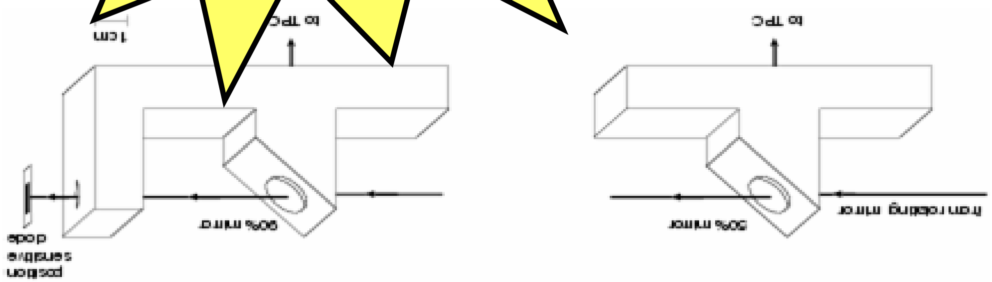


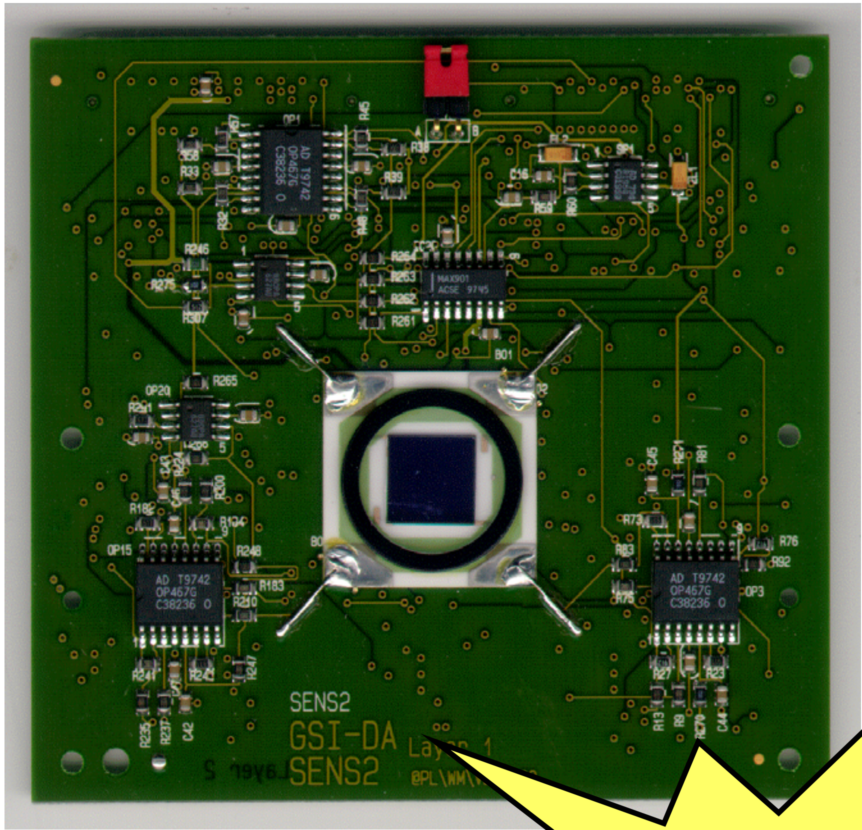


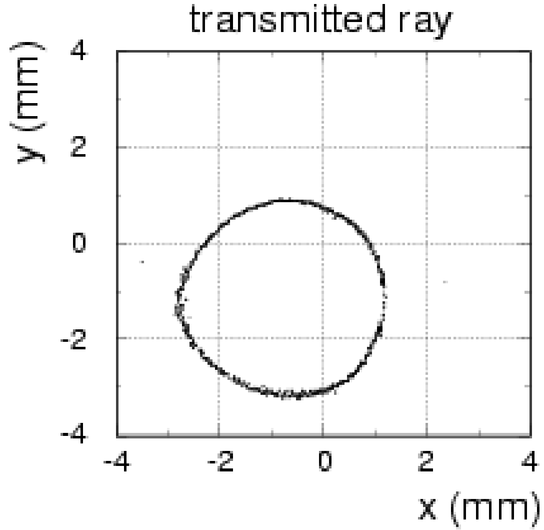
monitor the laser ray position before they enter the TPC

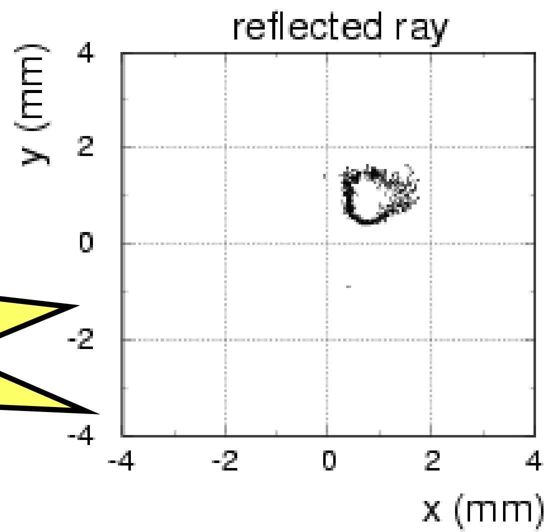




laser for TPC calibration

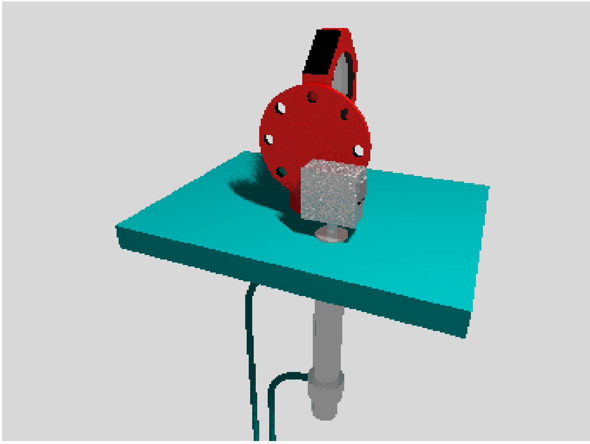


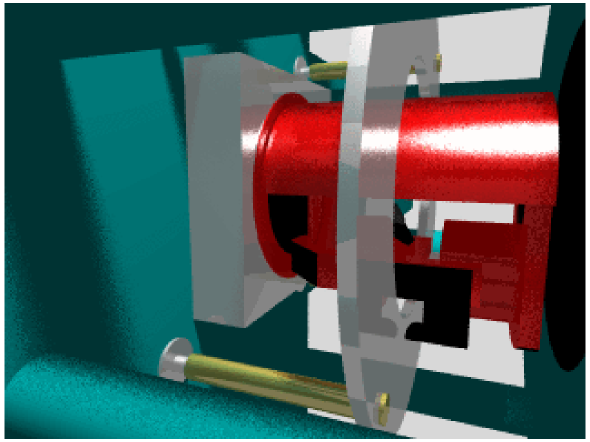


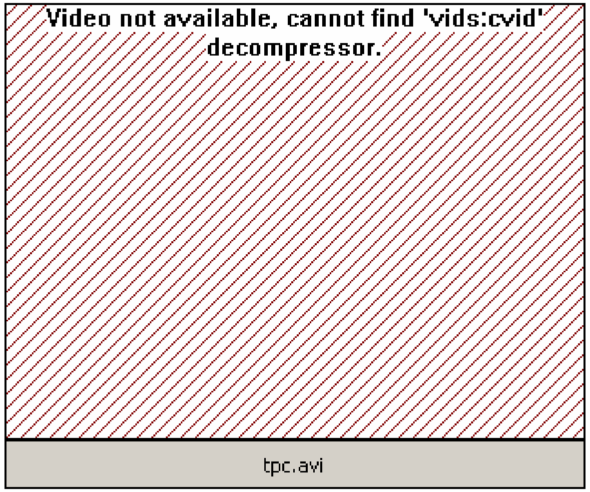


use diode info to make sure the ray is on the z-axis

laser for TPC calibration

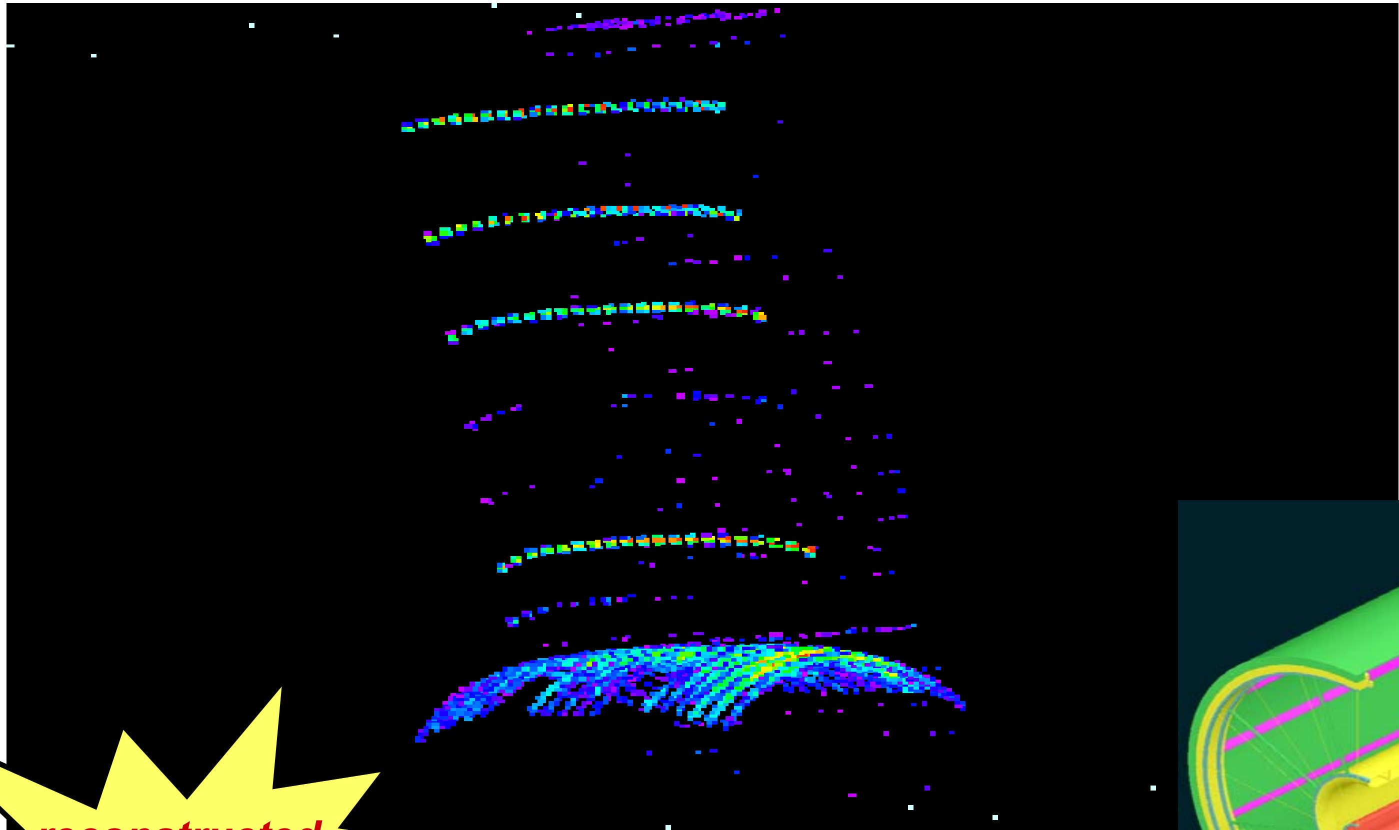


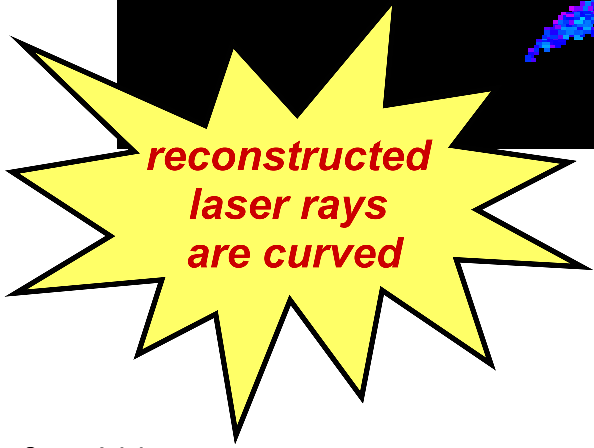




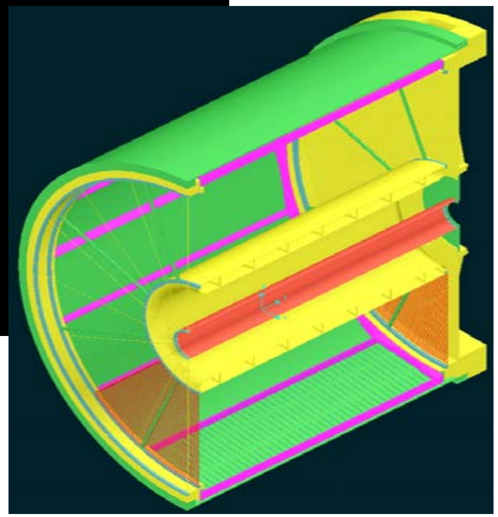
remove mirrors from z-axis during spill

first laser events in the CERES TPC

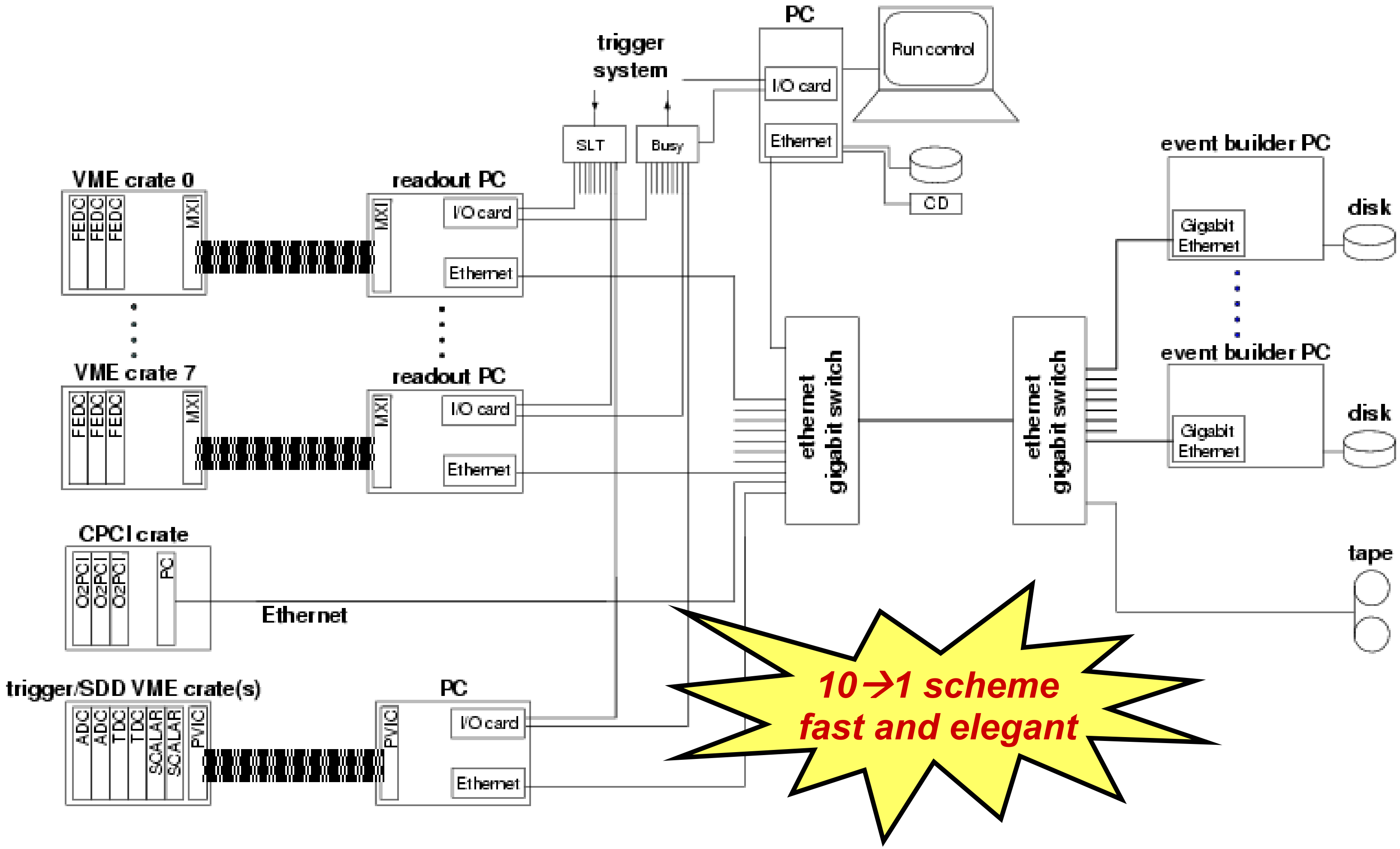




reconstructed laser rays are curved

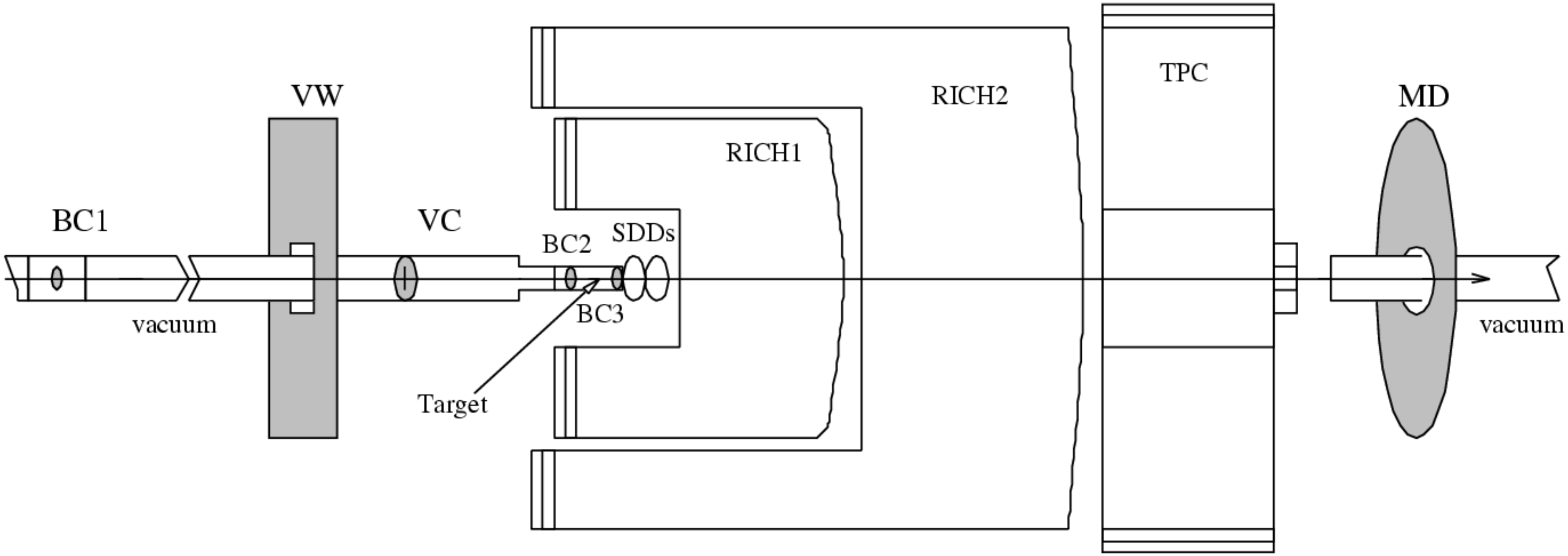


2000 run of CERES - DAQ

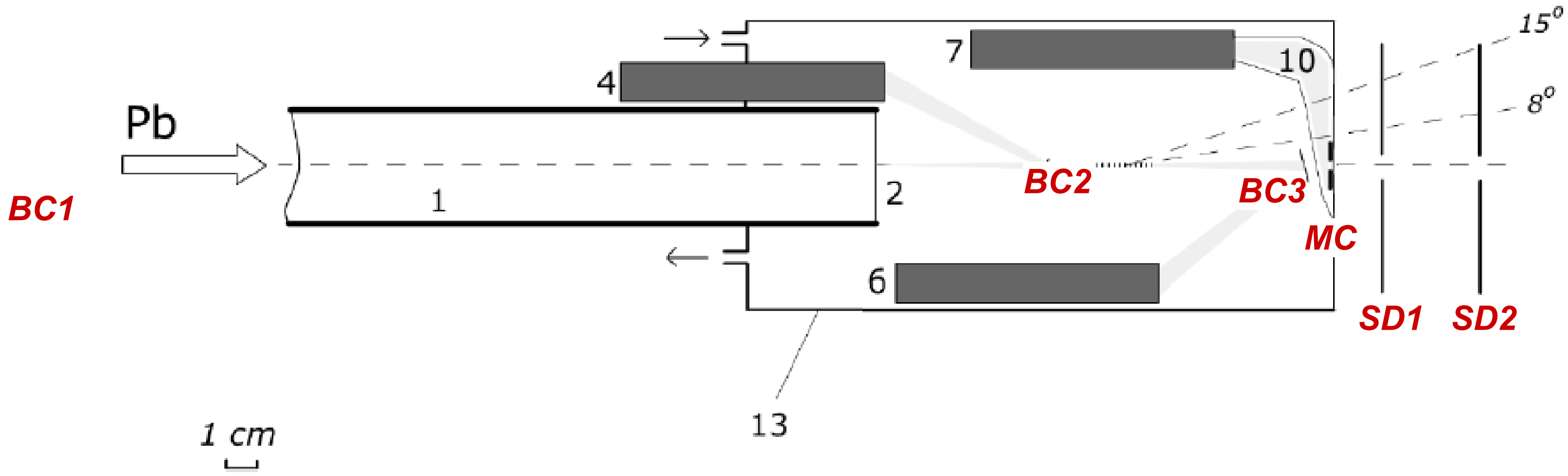


10 collecting PC's in spill (4.2 s) *300-400 event/spill*
in spill pause (15 s) sending to 1 of 7 receiving PC's
receiving PC merges the 10 streams into 1 file *200 MB/spill*
the file stored on CASTOR

2000 run of CERES - trigger



2000 run of CERES - trigger

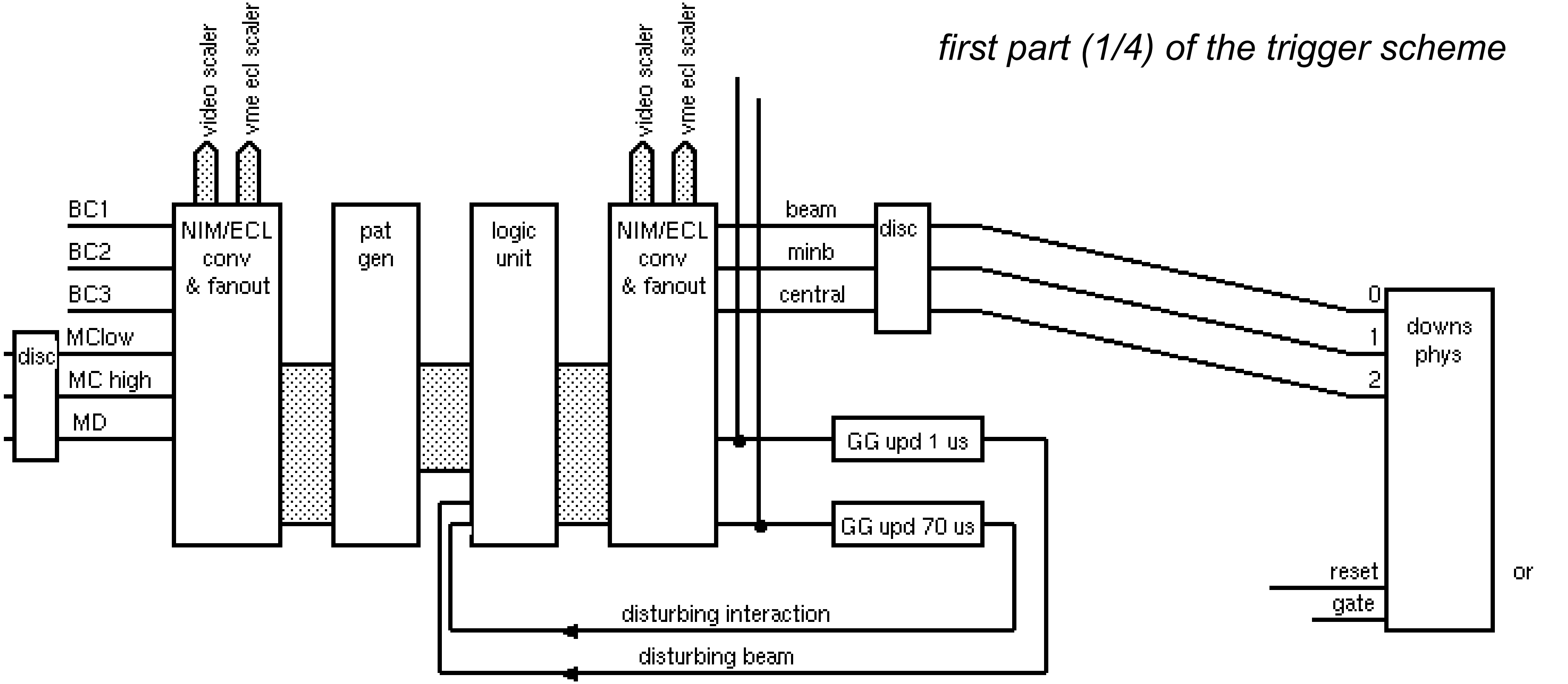


BC1	beam Cherenkov 1	centrality trigger with beam before-
BC2	beam Cherenkov 2	and after-protection
target		
BC3	beam Cherenkov 3	
MC	multiplicity counter	
BC1*2	beam	
BC1*2*^3	minb	
BC1*2*^3*MC	central	

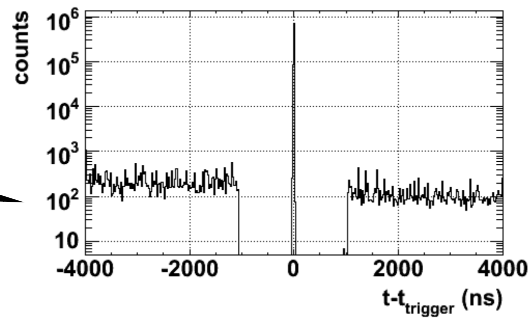
air Cherenkov
guru V. Yurevich

2000 run of CERES - trigger

first part (1/4) of the trigger scheme



the simplest beam-before-protection system in the world: one gate generator



2000 run of CERES - trigger

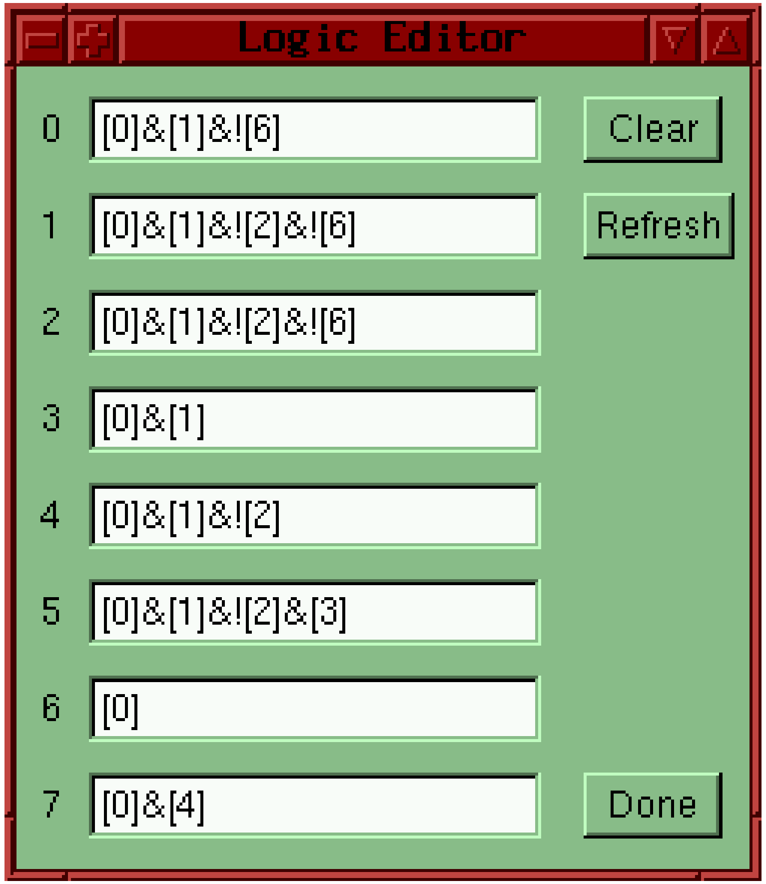
old scheme:
- *VME modules controlled by an old FIC processor*

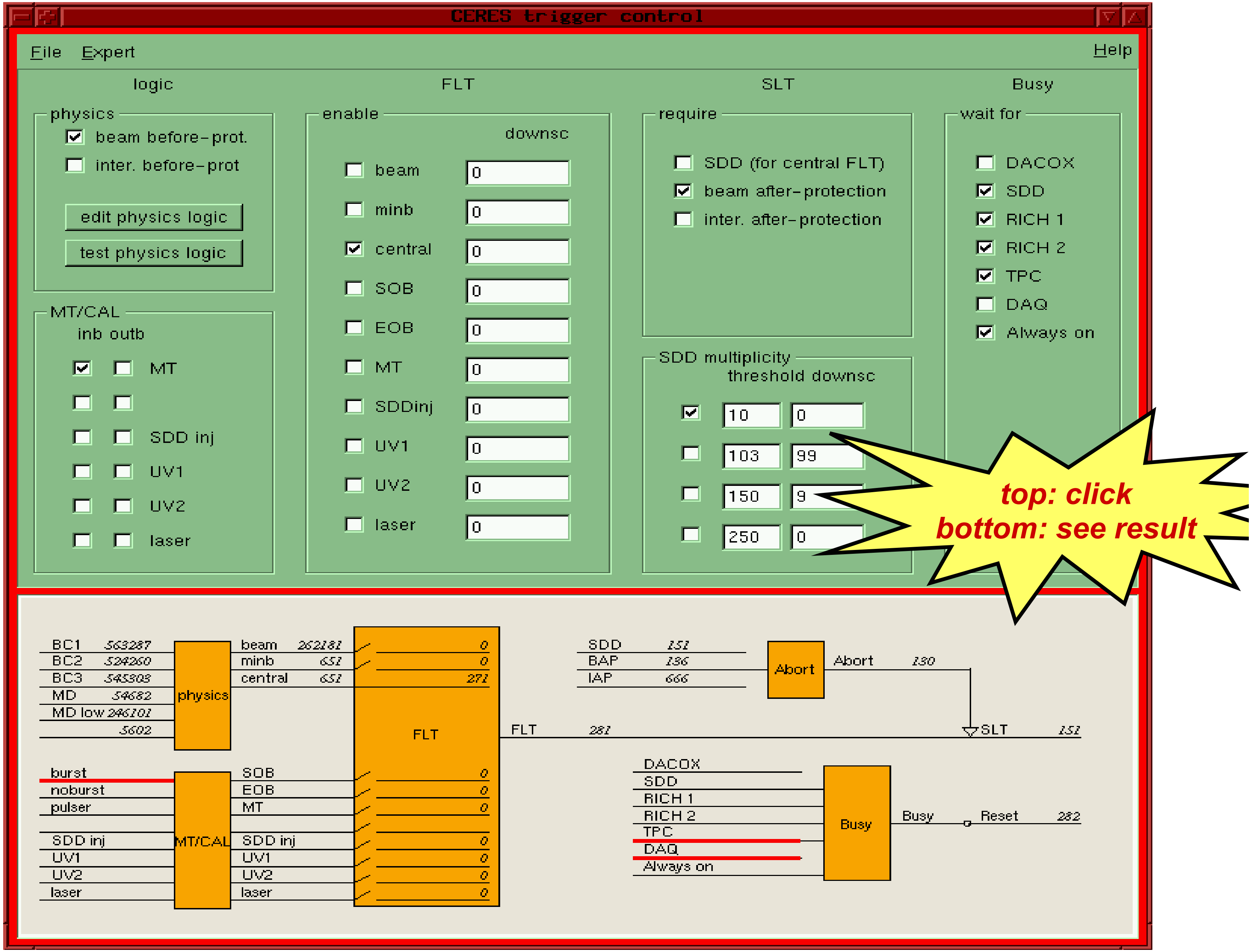
new scheme:
- *old FIC processor just forwards read and write commands to VME modules (server)*
- *client software on Linux*

split:

simple server talking to the hardware

all the rest on linux

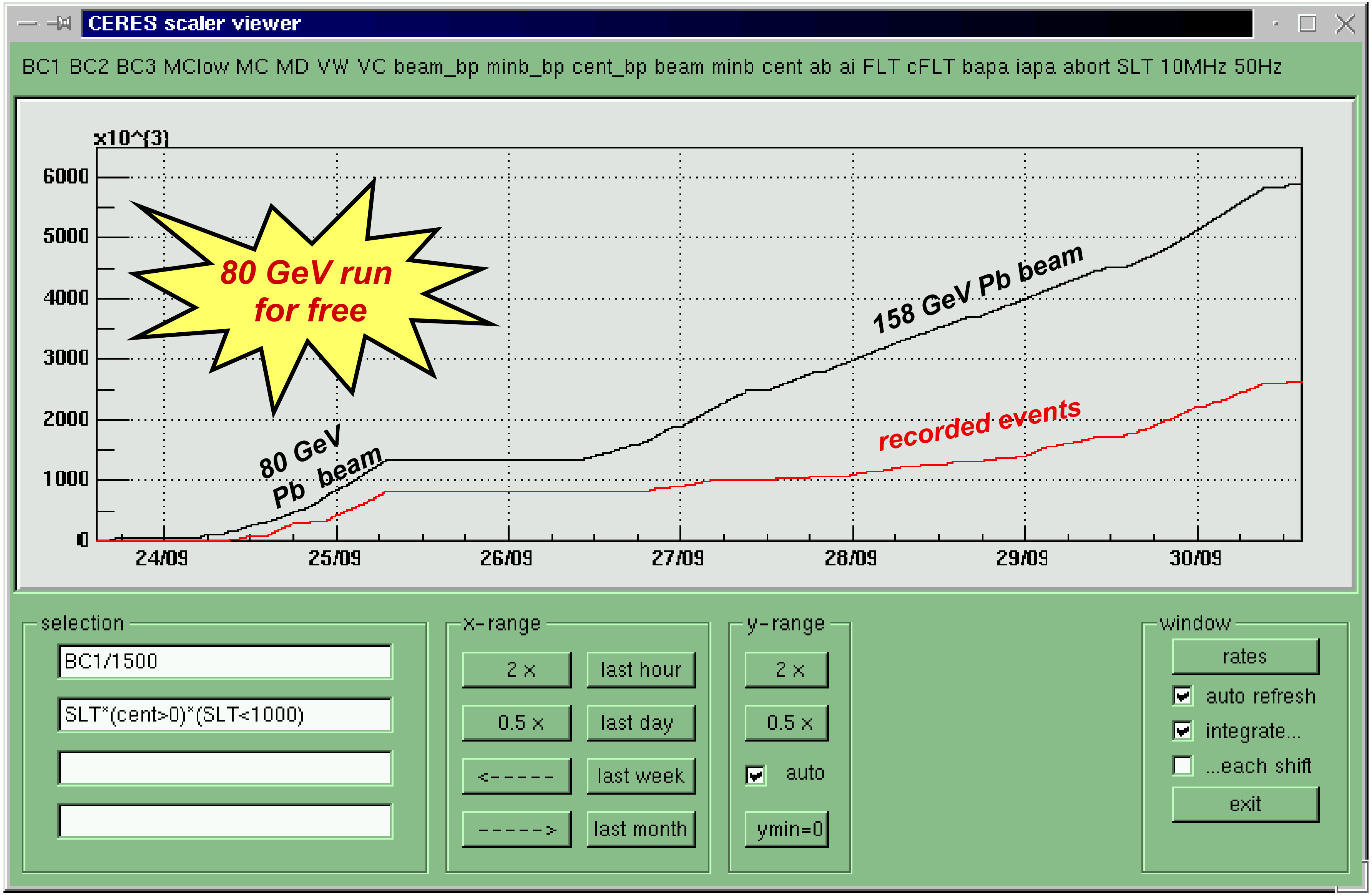



CERES trigger control
File
Expert
Help
logic
FLT
SLT
Busy
physics
beam before-prot.
inter. before-prot
edit physics logic
test physics logic
MT/CAL
inb outb
MT
SDD inj
UV1
UV2
laser
enable
downsc
beam
minb
central
SOB
EOB
MT
SDDinj
UV1
UV2
laser
require
SDD (for central FLT)
beam after-protection
inter. after-protection
SDD multiplicity
threshold downsc
10
103
99
150
9
250
wait for
DACOX
SDD
RICH 1
RICH 2
TPC
DAQ
Always on
top: click
bottom: see result
BC1 563287
BC2 524260
BC3 545303
MD 54682
MD low 246101
5602
physics
beam 262181
minb 651
central 651
271
FLT
FLT 281
SDD 151
BAP 136
IAP 666
Abort
Abort 130
SLT 151
burst
noburst
pulser
SDD inj
UV1
UV2
laser
MT/CAL
SOB
EOB
MT
SDD inj
UV1
UV2
laser
DACOX
SDD
RICH 1
RICH 2
TPC
DAQ
Always on
Busy
Busy
Reset 282

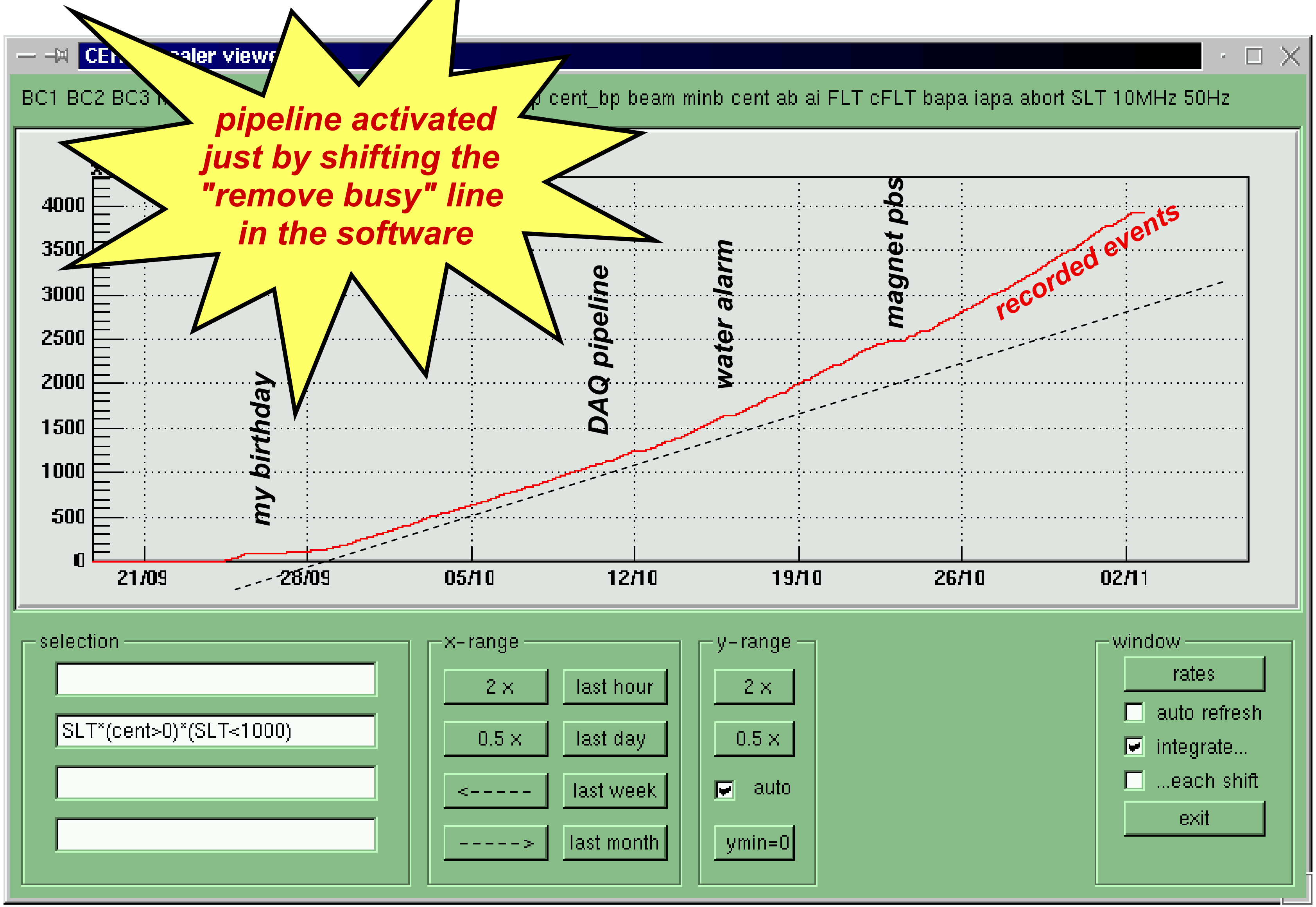

CERES scaler viewer
BC1 BC2 BC3 MD MDlow VC VW beam_bp minb_bp cent_bp beam minb cent ab ai FLT cFLT SDDa bapa iapa abort SLT 10MHz 50Hz
x10 2
1600
1400
1200
1000
800
600
400
200
0
09h00
09h15
09h30
09h45
10h00
10h15
10h30
10h45
selection
beam
minb*100
range
2 x
last hour
0.5 x
last day
<-----
last week
----->
last month
window
rates
exit
including formulae

2000 run of CERES

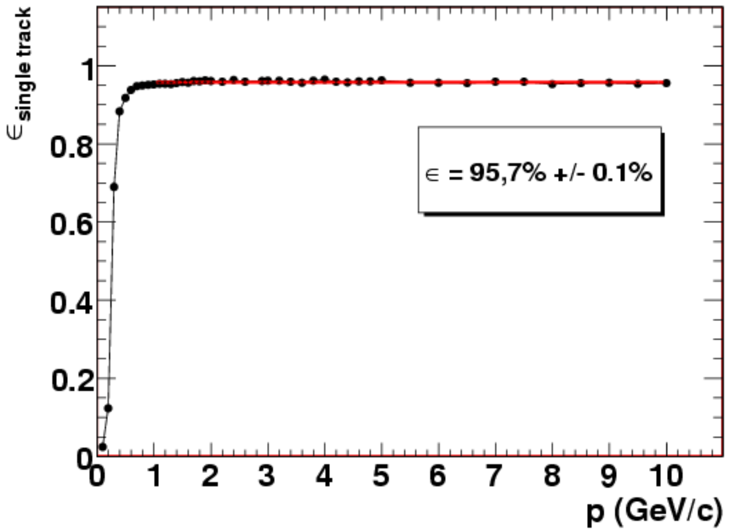
Total events vs time

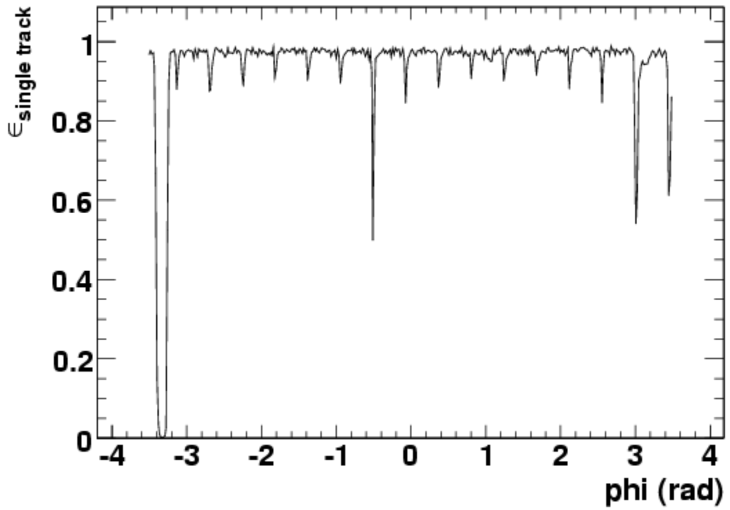


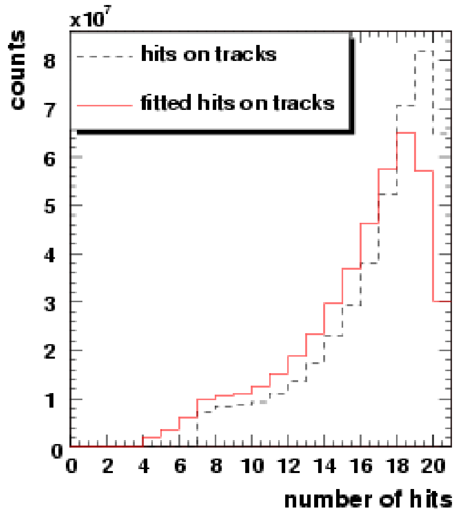
2000 run of CERES



TPC performance





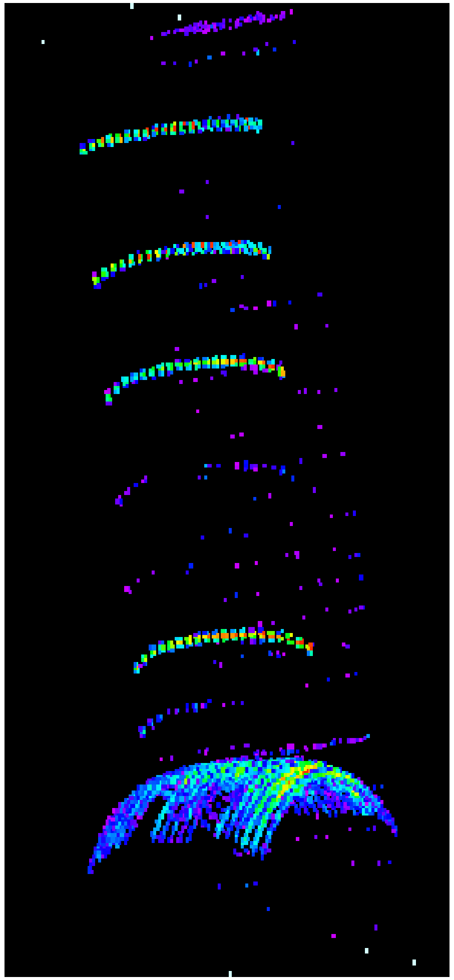


TPC electric field

- ***laser tracks curved***

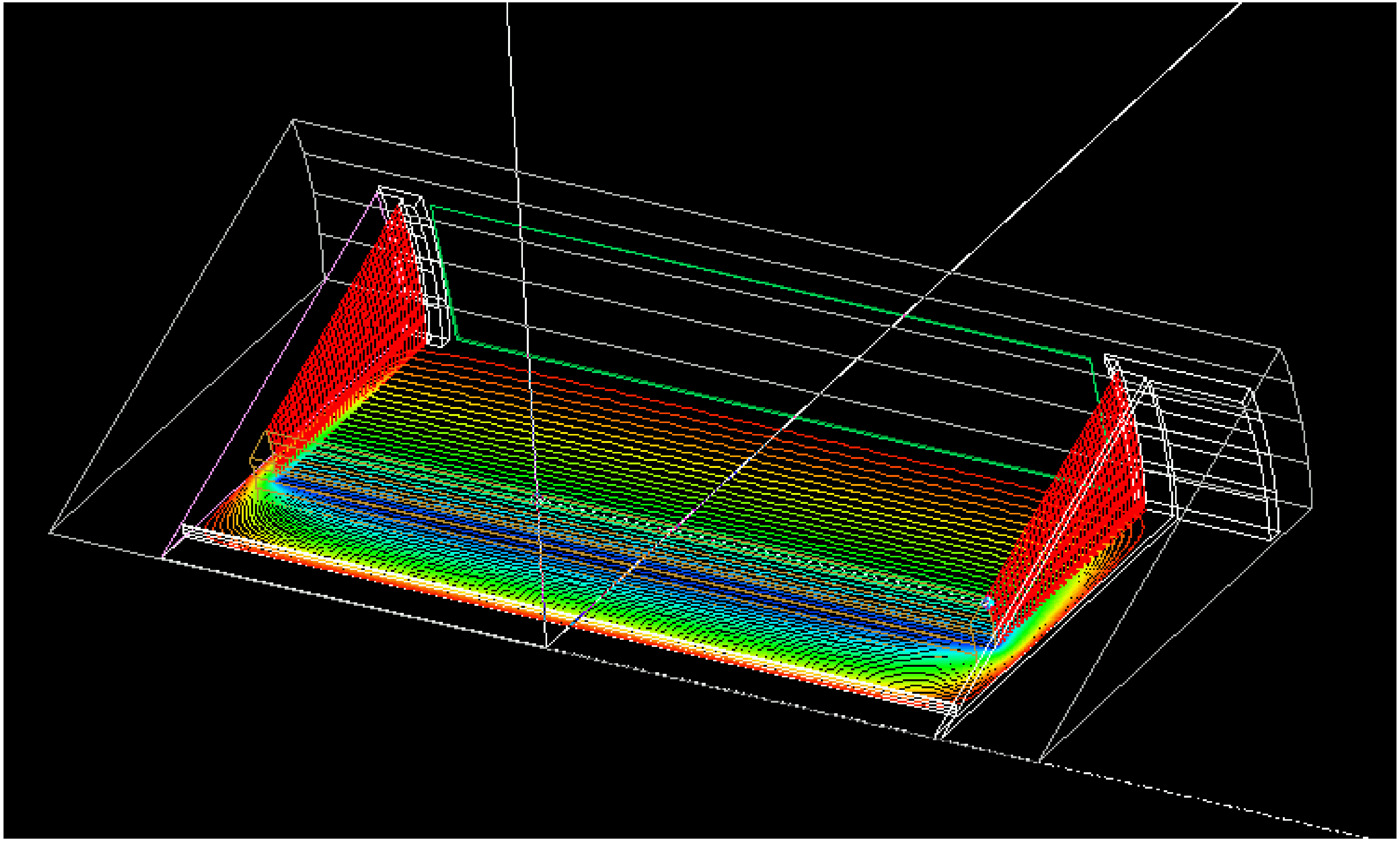
  → field is "wrong"

  → better calculation needed

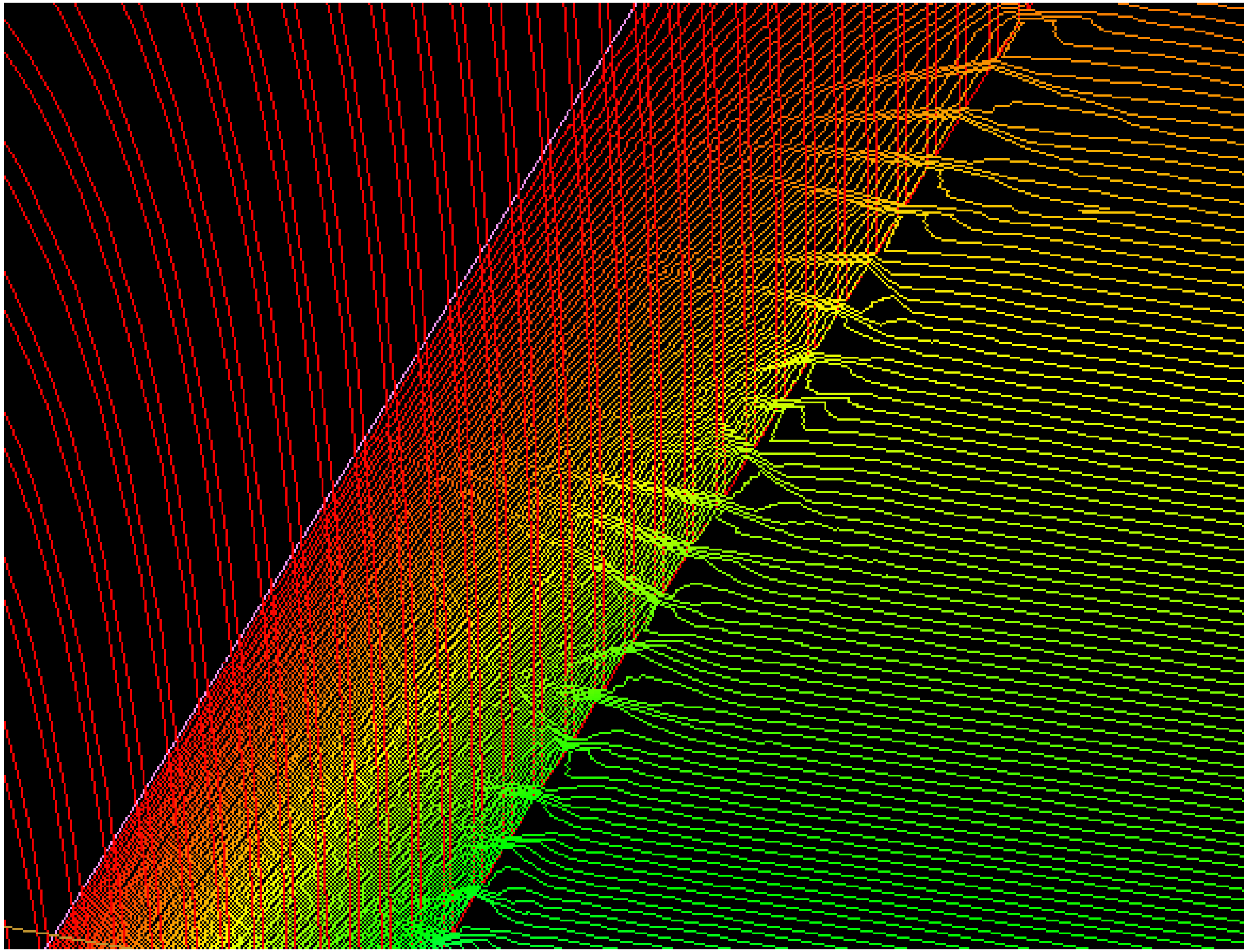


TPC electric field: calculate in 3d

Maxwell package at CERN



TPC electric field: calculate in 3d



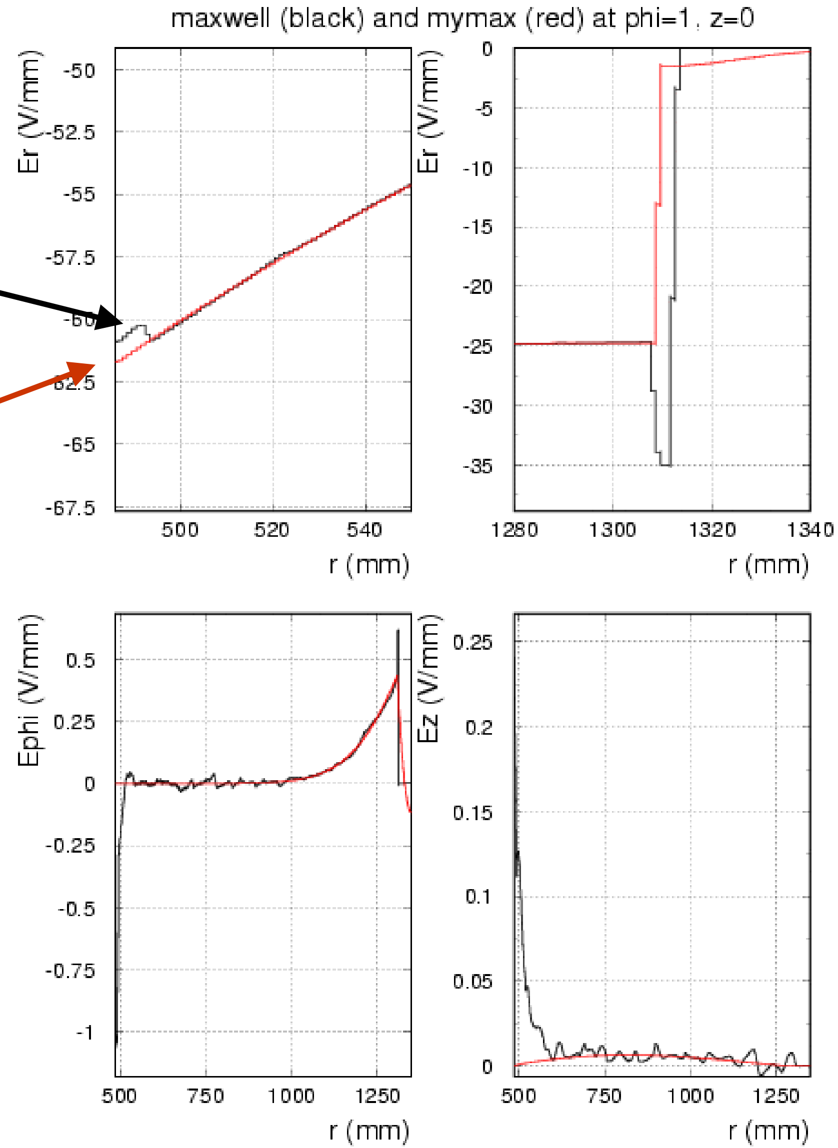
finite width of the stripes!

TPC electric field: calculate precisely!

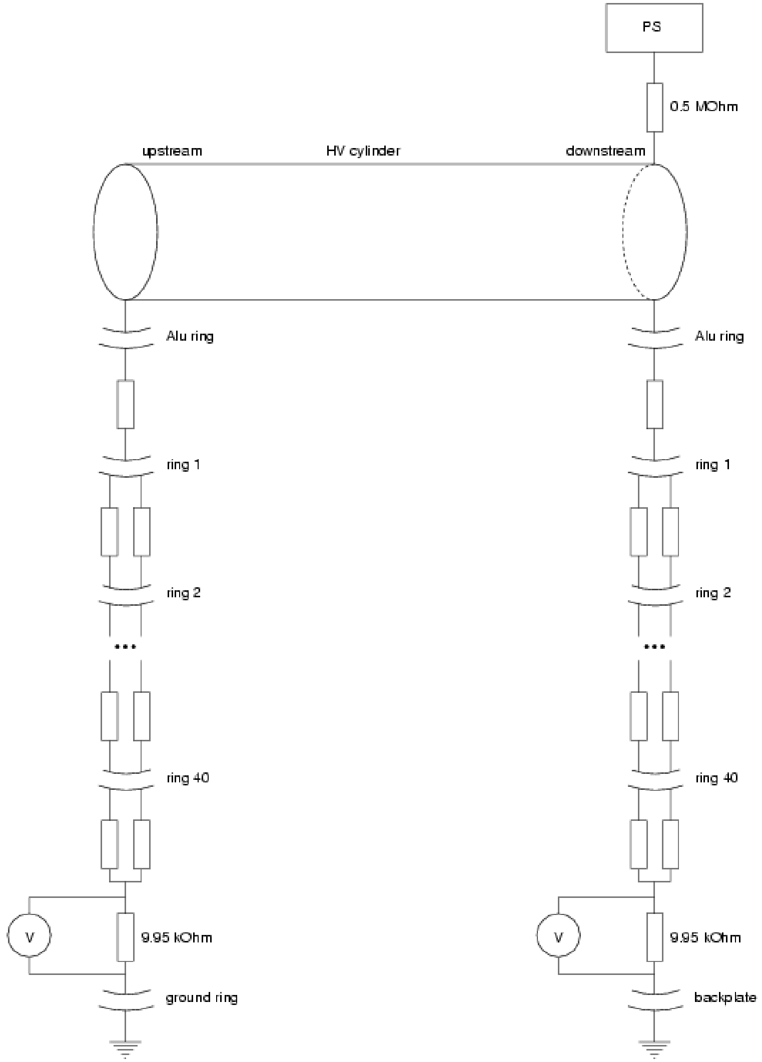
maxwell package: bumps

custom calculation: perfect

"smoothing" works great

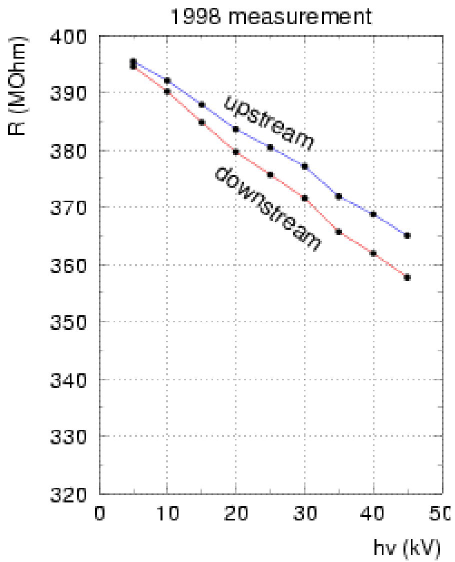


TPC electric field: account for bad resistors!

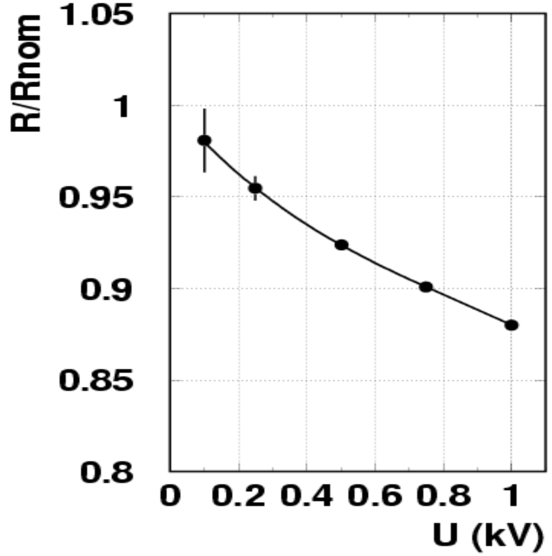


resistance of

full resistor chain

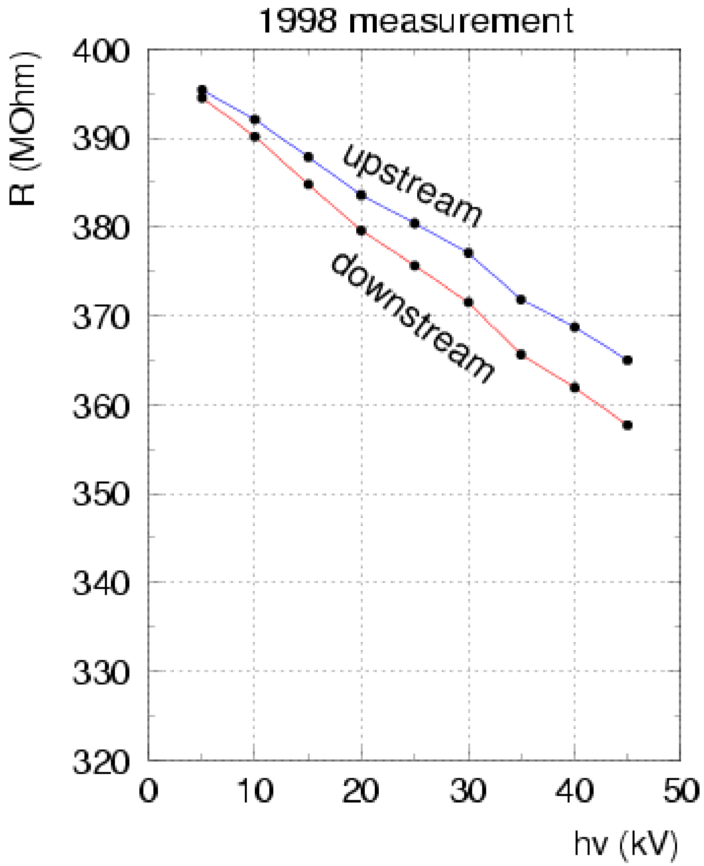


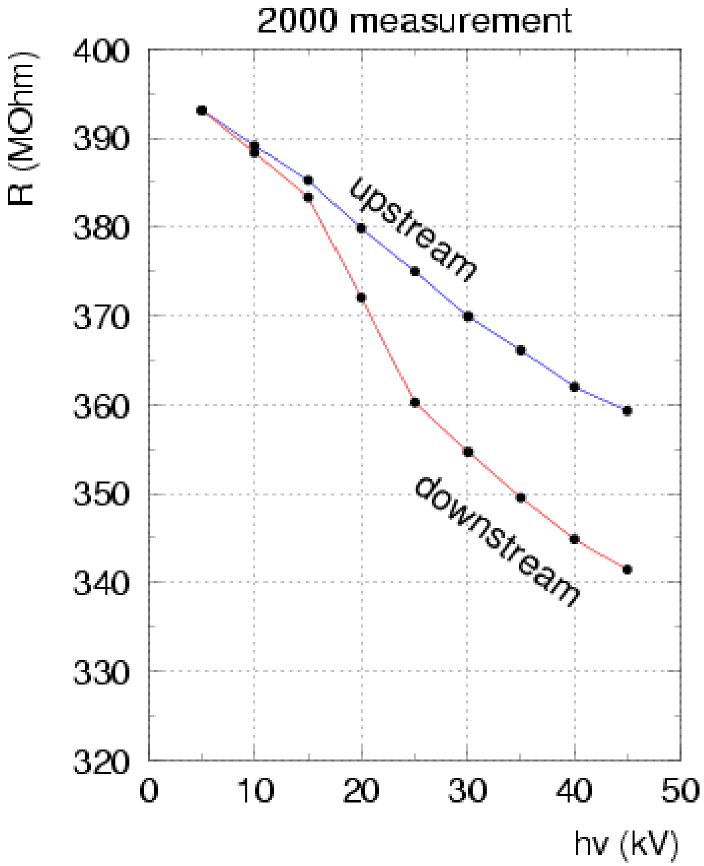
single carbon resistor (CERN stock)



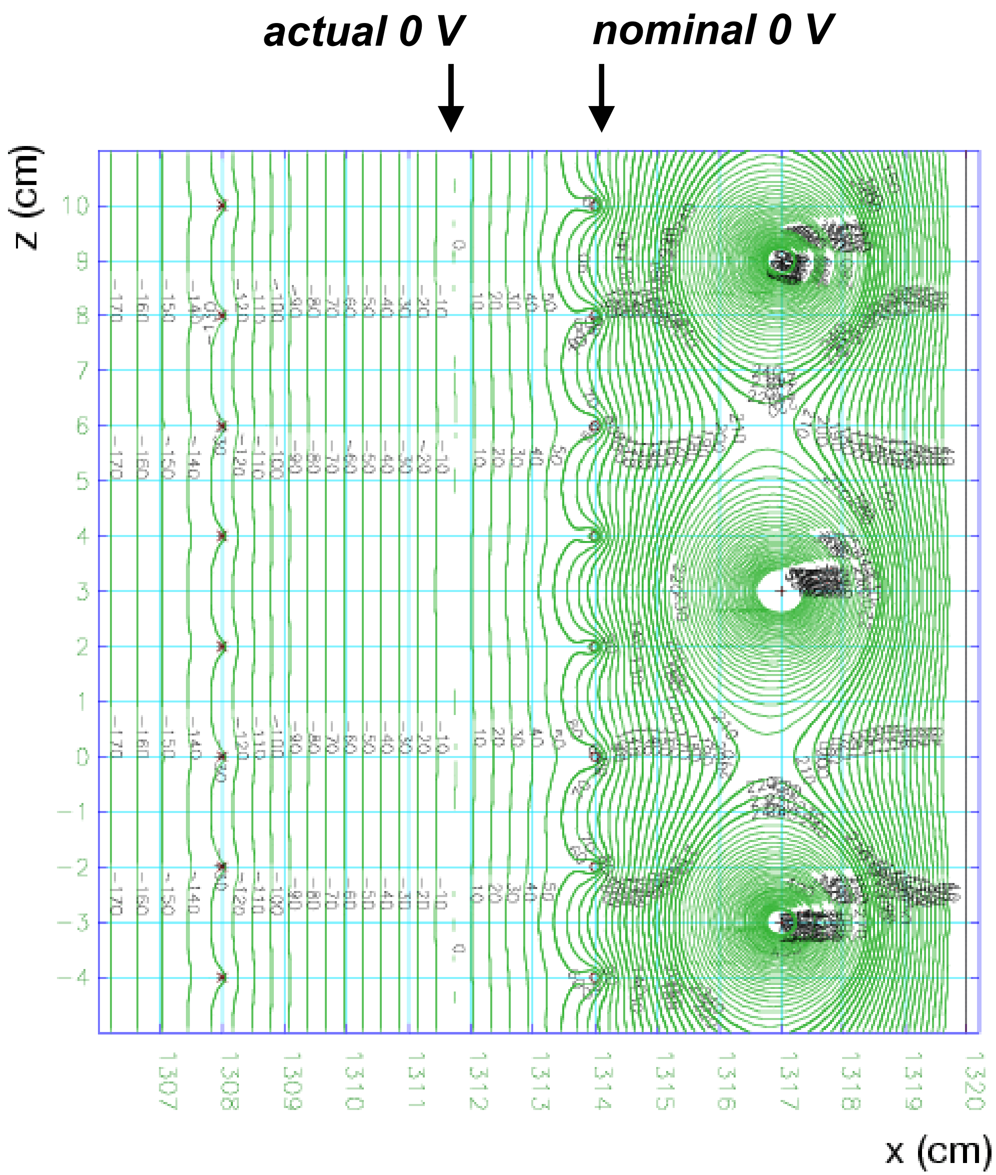
bad luck with resistors

TPC electric field: short in the resistor chain!



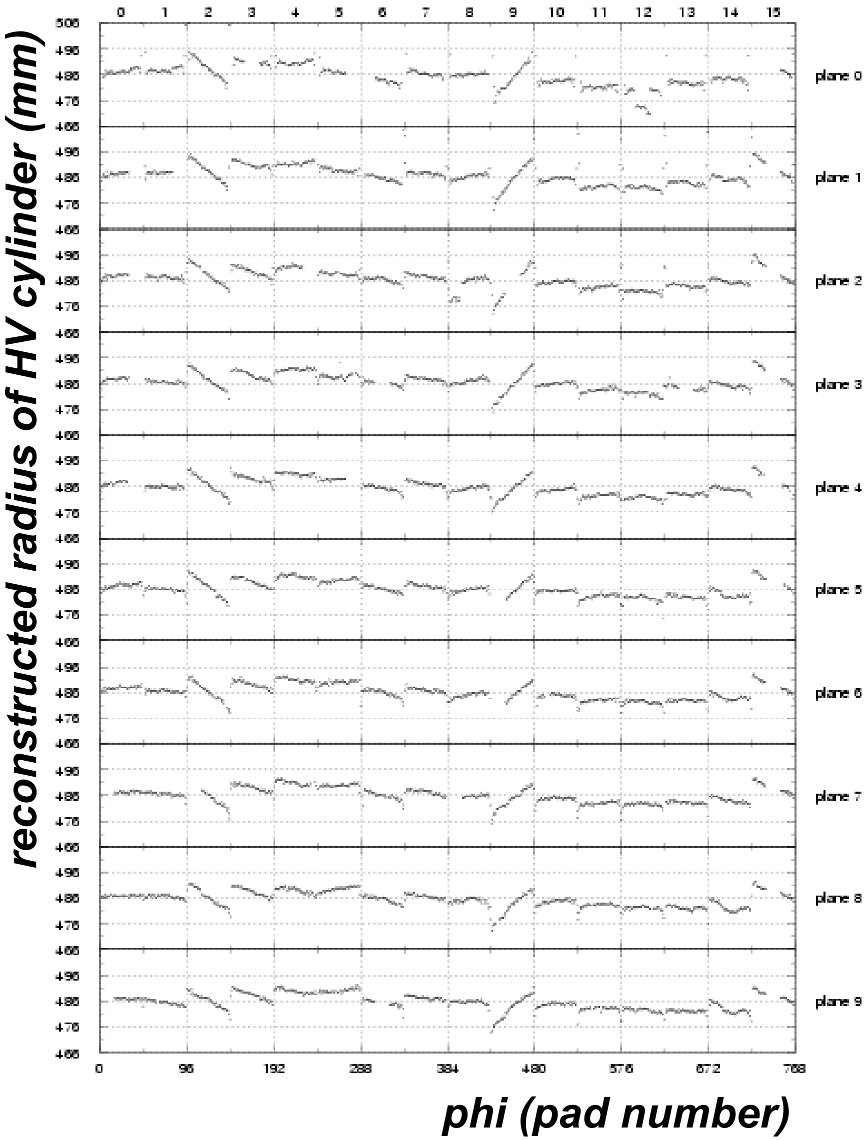


TPC electric field: leaking through wires!



2-d Garfield calculation including wires matched to the 3-d calculation of the drift volume

TPC electric field: chambers misaligned



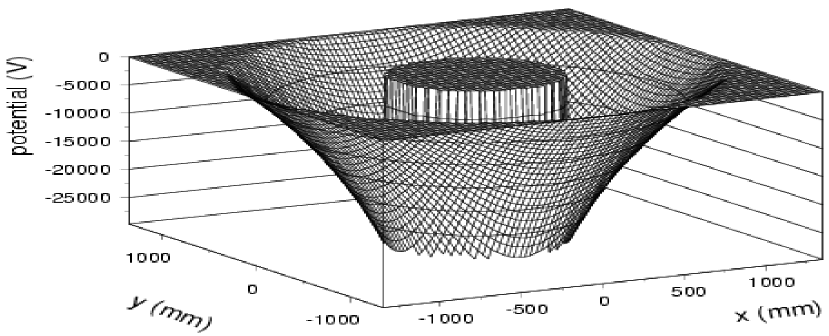
effect of chamber misalignment:

1. drift path modified

2. drift field modified

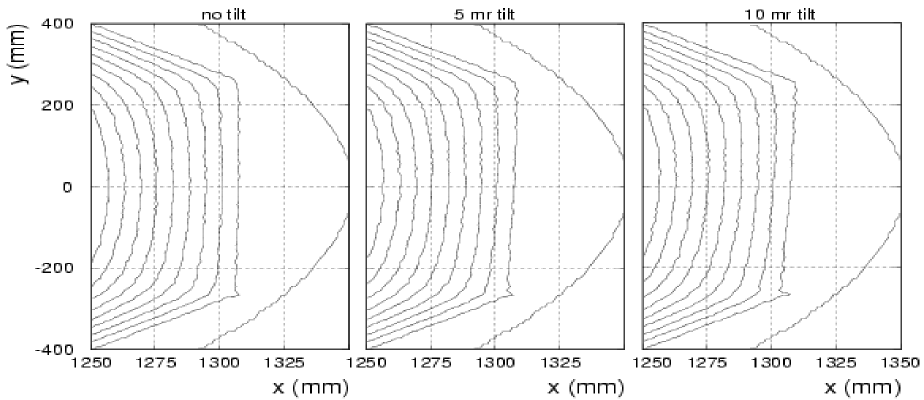
(similar contributions, same sign)

TPC electric field: chamber misalignment corrected



1. calculate 2-dim potential with nominal geometry $V_{2,nominal}$

2. calculate 2-dim potential with misaligned chamber $V_{2,misal}$

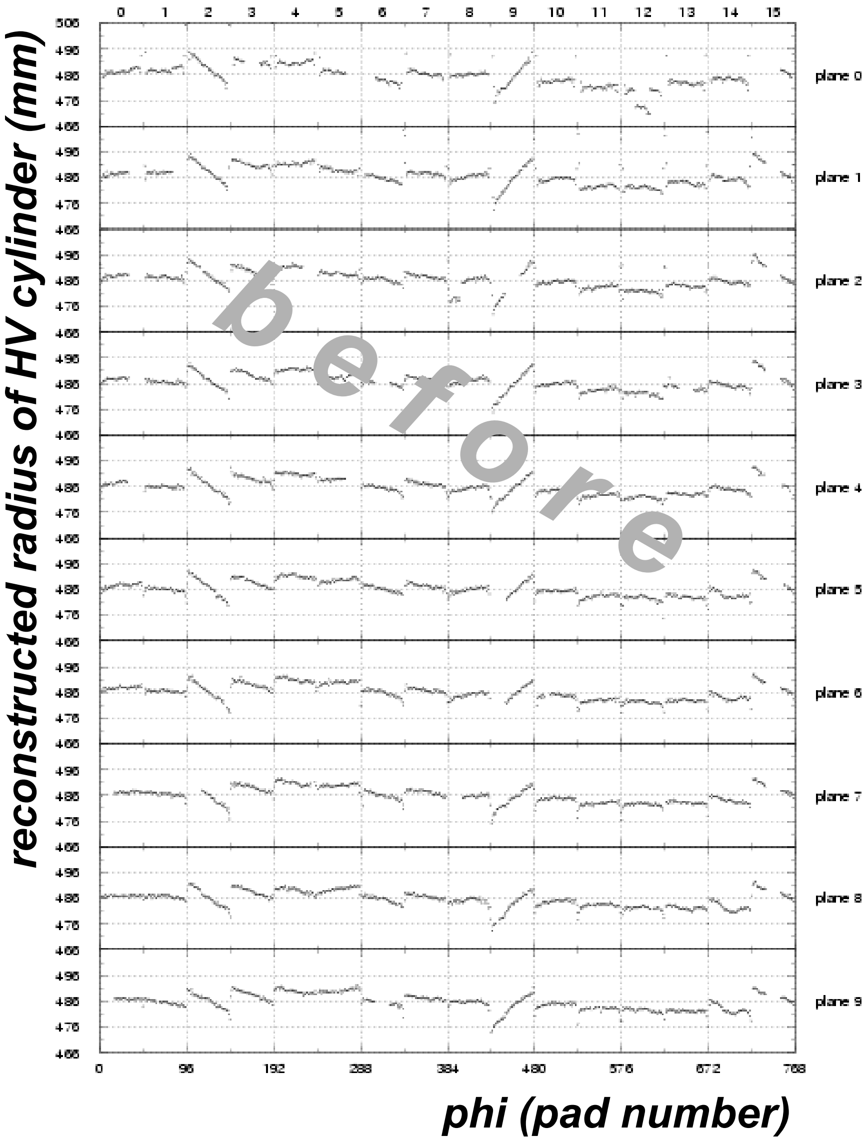


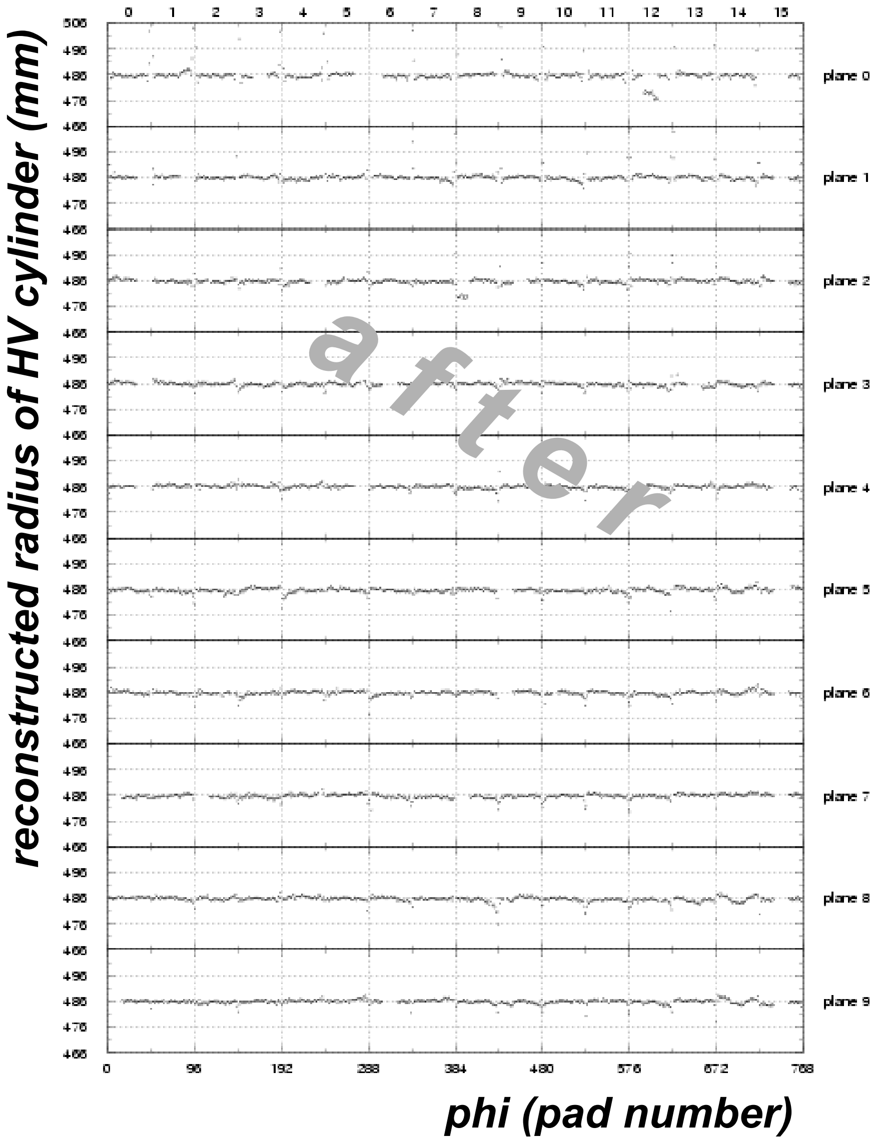
3. calculate corrected 3-dim potential as

$$V_{3cor} = V_3 + V_{2,misal} - V_{2,nominal}$$

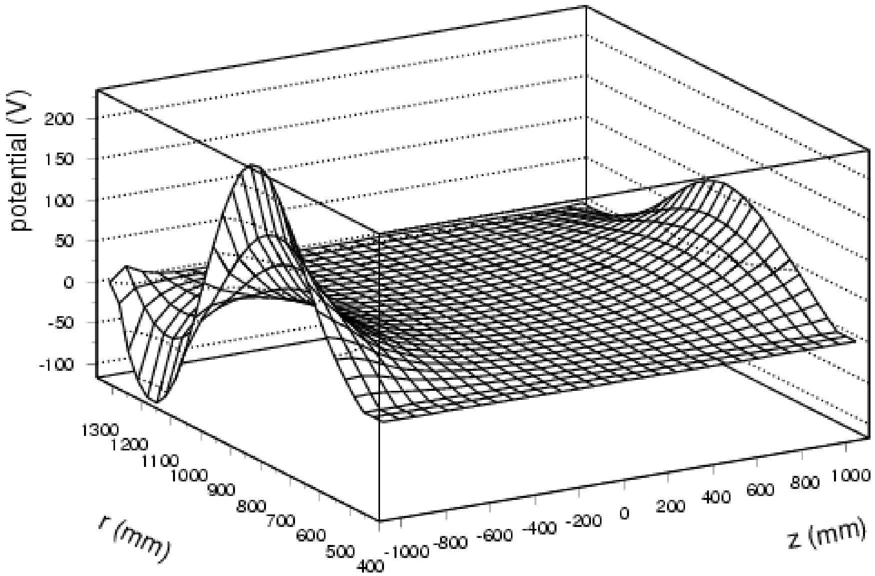
iterate misalignment until reconstructed cylinder has R = 486 mm

TPC electric field: chamber misalignment corrected



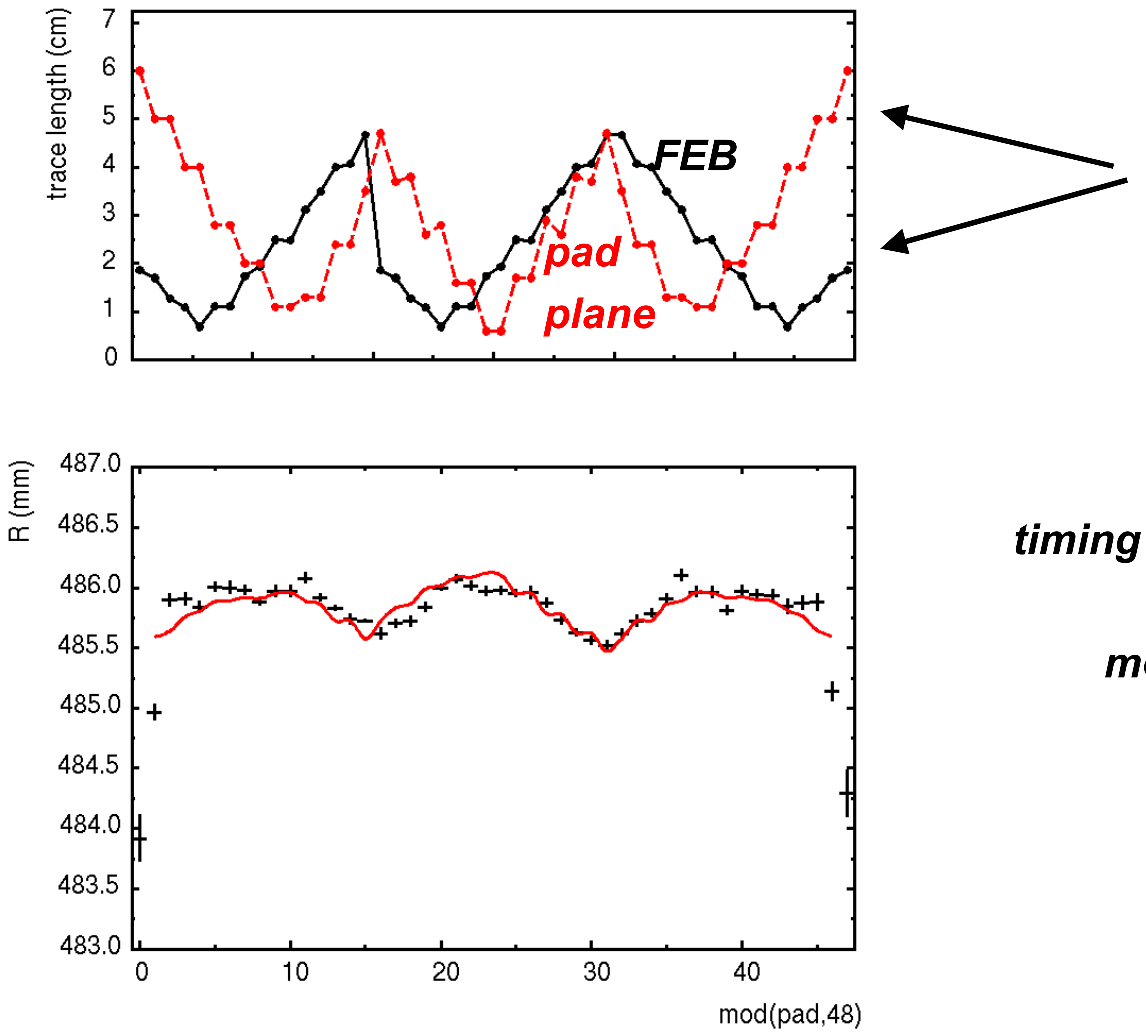


TPC electric field: residual correction



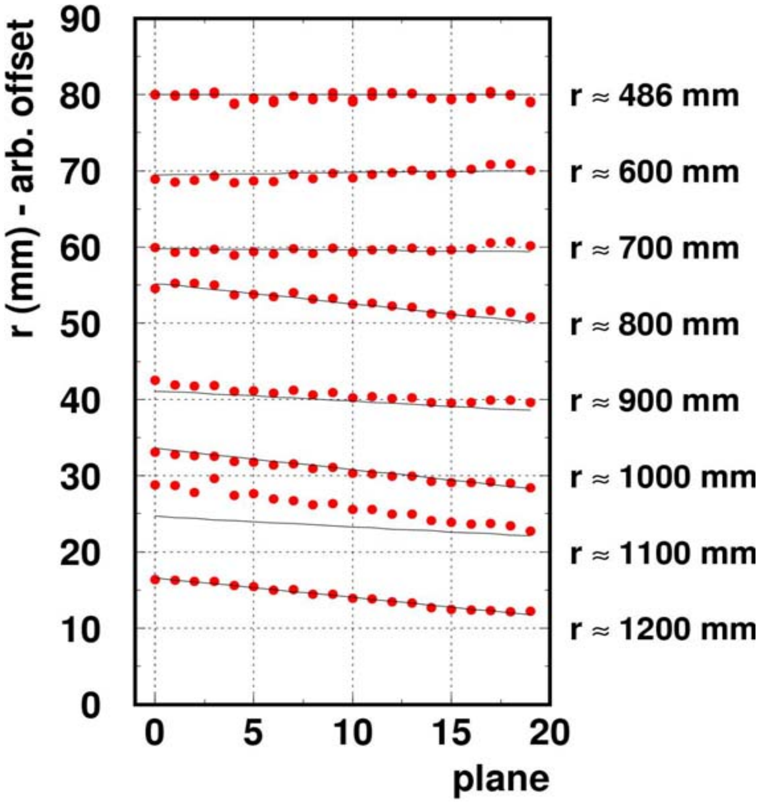
ring voltages adjusted to remove the remaining curvature of laser tracks

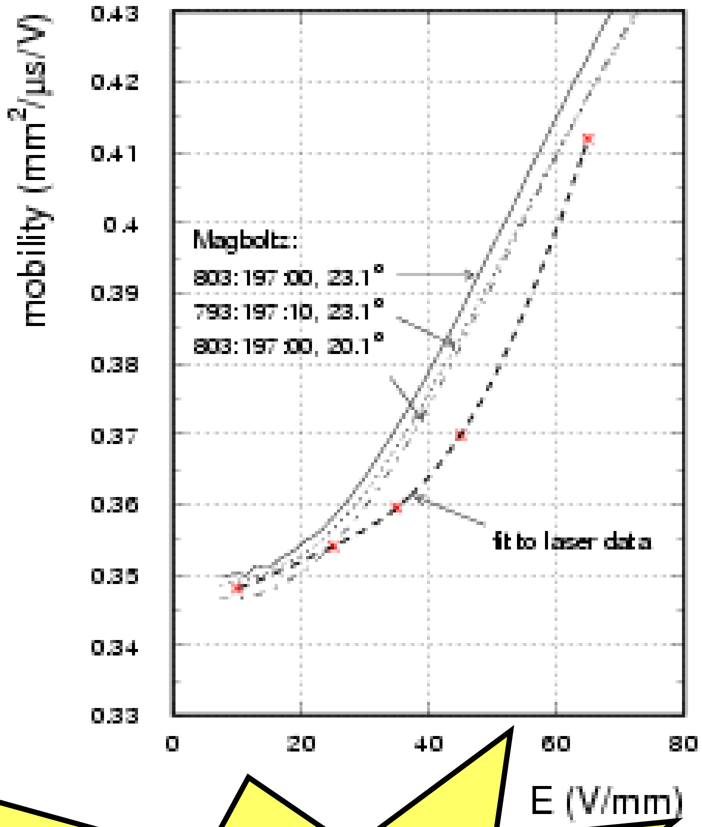
drift time: effect of the trace length



trace lengths
affects
capacitance
affects
pulse shape
affects
timing of the amplified pulse
affects
measured drift time

drift velocity determination with laser tracks



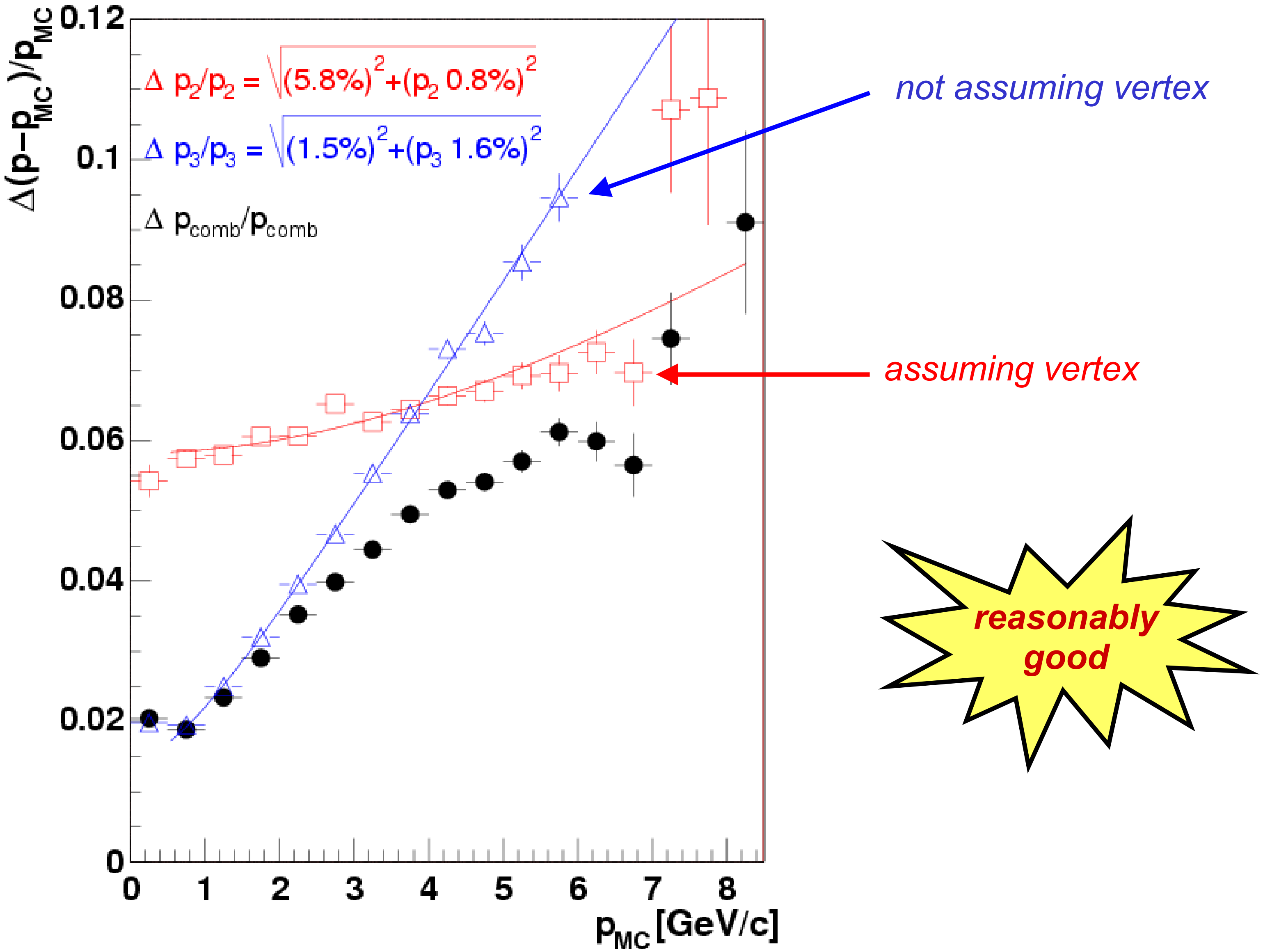


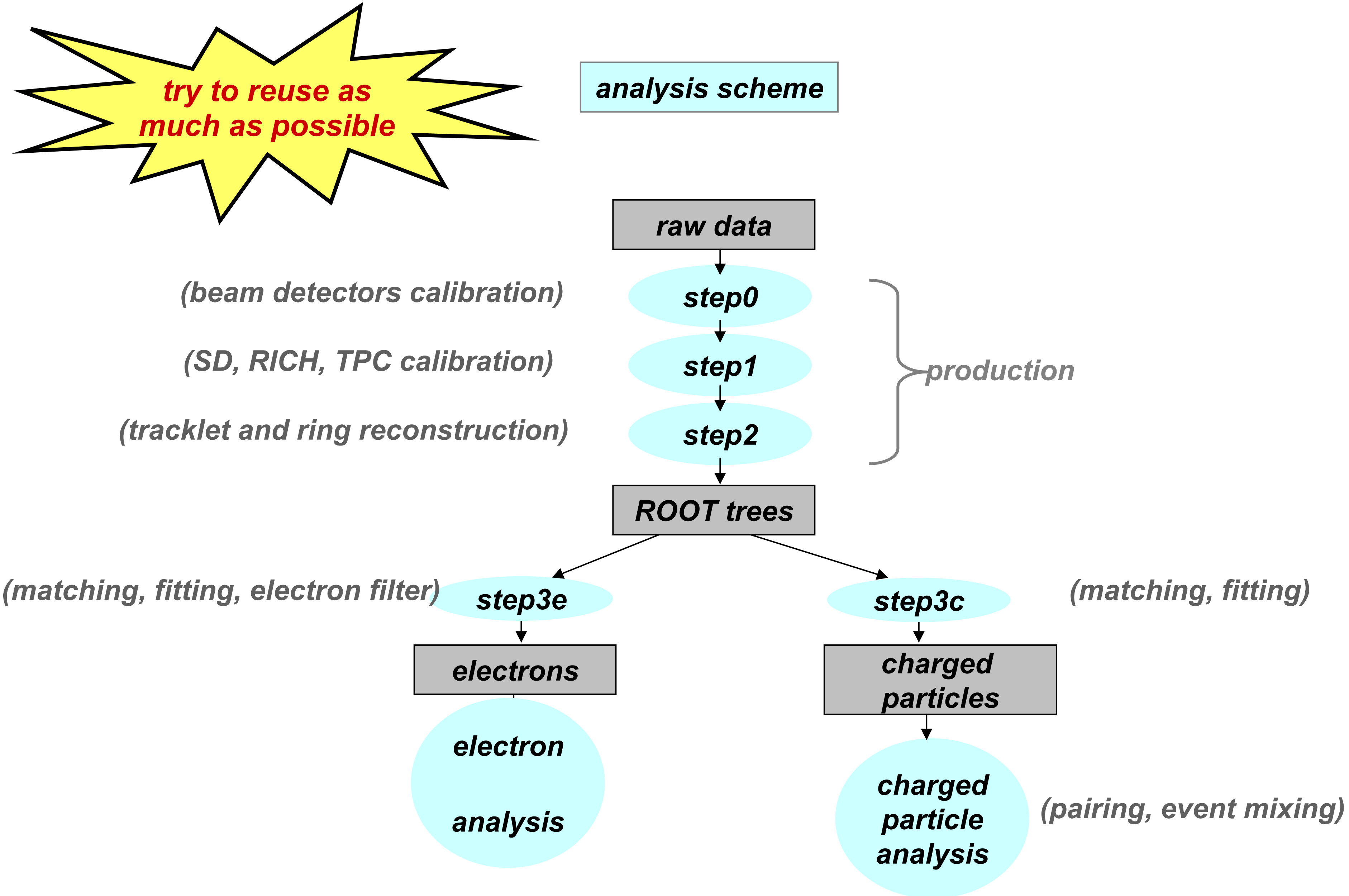
lines: *absolute laser ray positions known from the laser system*

points: hits reconstructed by the (calibrated) TPC

drift velocity different from the one calculated by Magboltz

final momentum resolution



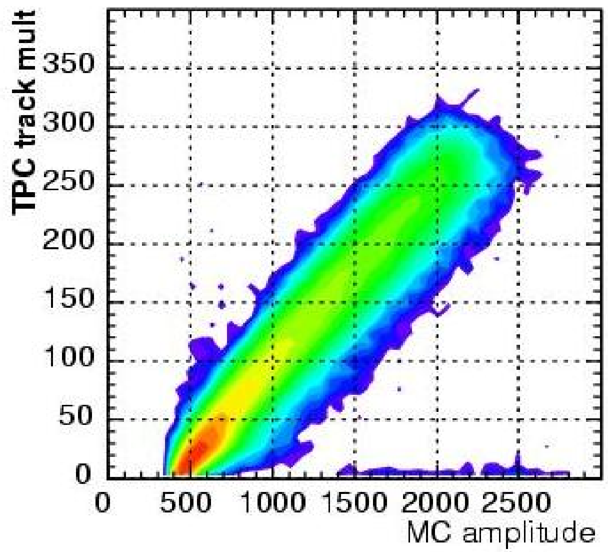

try to reuse as
much as possible
analysis scheme
raw data
(beam detectors calibration)
step0
(SD, RICH, TPC calibration)
step1
(tracklet and ring reconstruction)
step2
production
ROOT trees
(matching, fitting, electron filter)
step3e
step3c
(matching, fitting)
electrons
charged
particles
electron
analysis
charged
particle
analysis
(pairing, event mixing)

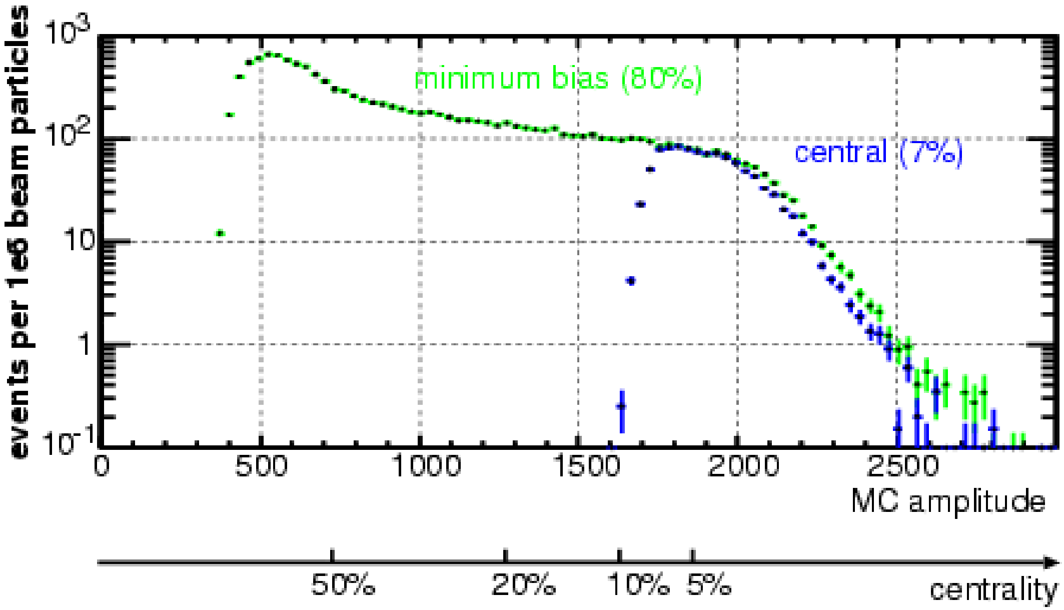
centrality determination

Pb+Au at 158 GeV per nucleon

centrality deduced from the multiplicity of charged particles around mid-rapidity

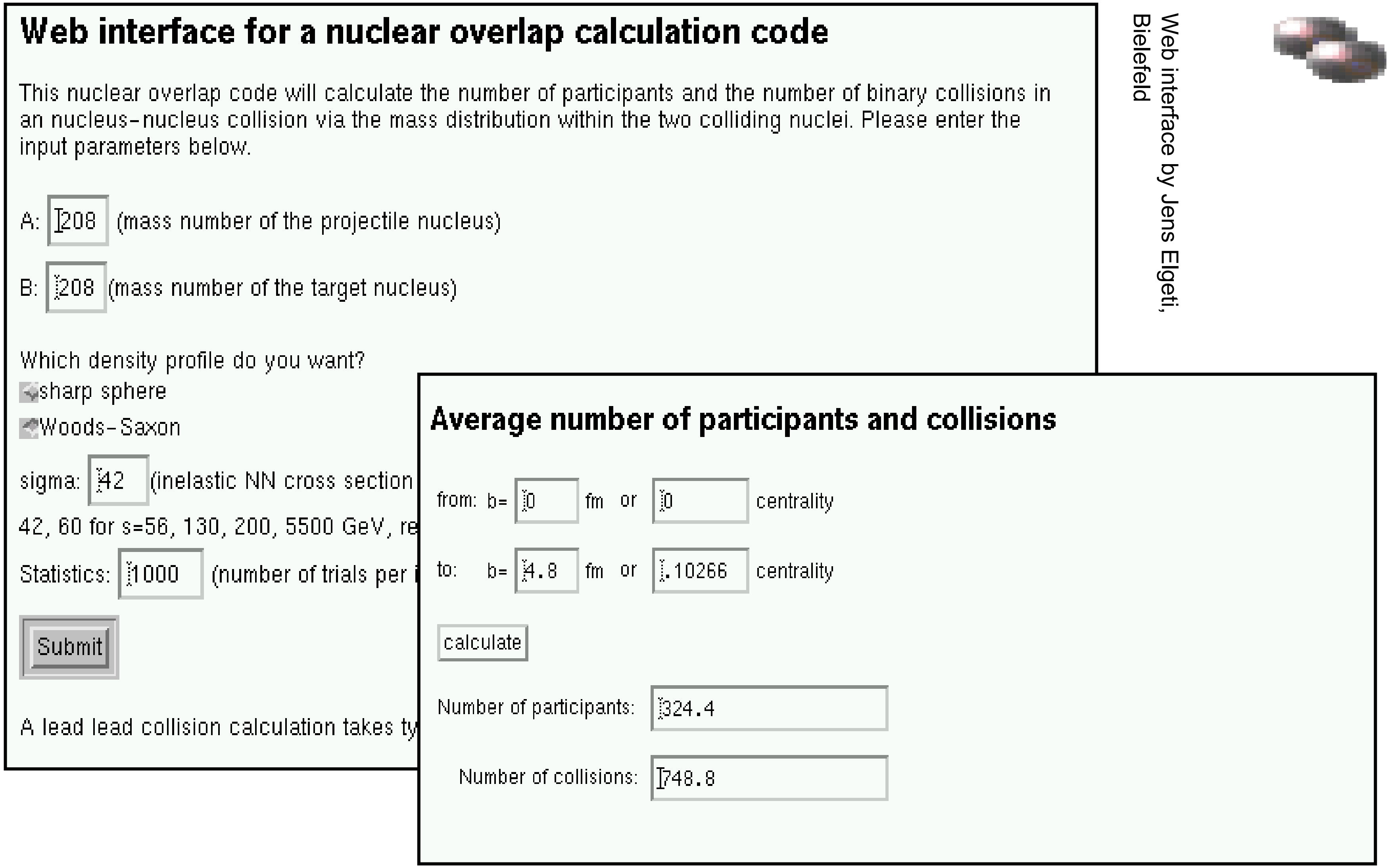
MC scintillator amplitude $2.95 < \eta < 4.05$
TPC track multiplicity $2.10 < \eta < 2.80$
mid-rapidity $y = 2.91$





nuclear overlap on the web

http://www.gsi.de/~misko/overlap



Web interface by Jens Elgeti, Bielefeld

charged particle multiplicity

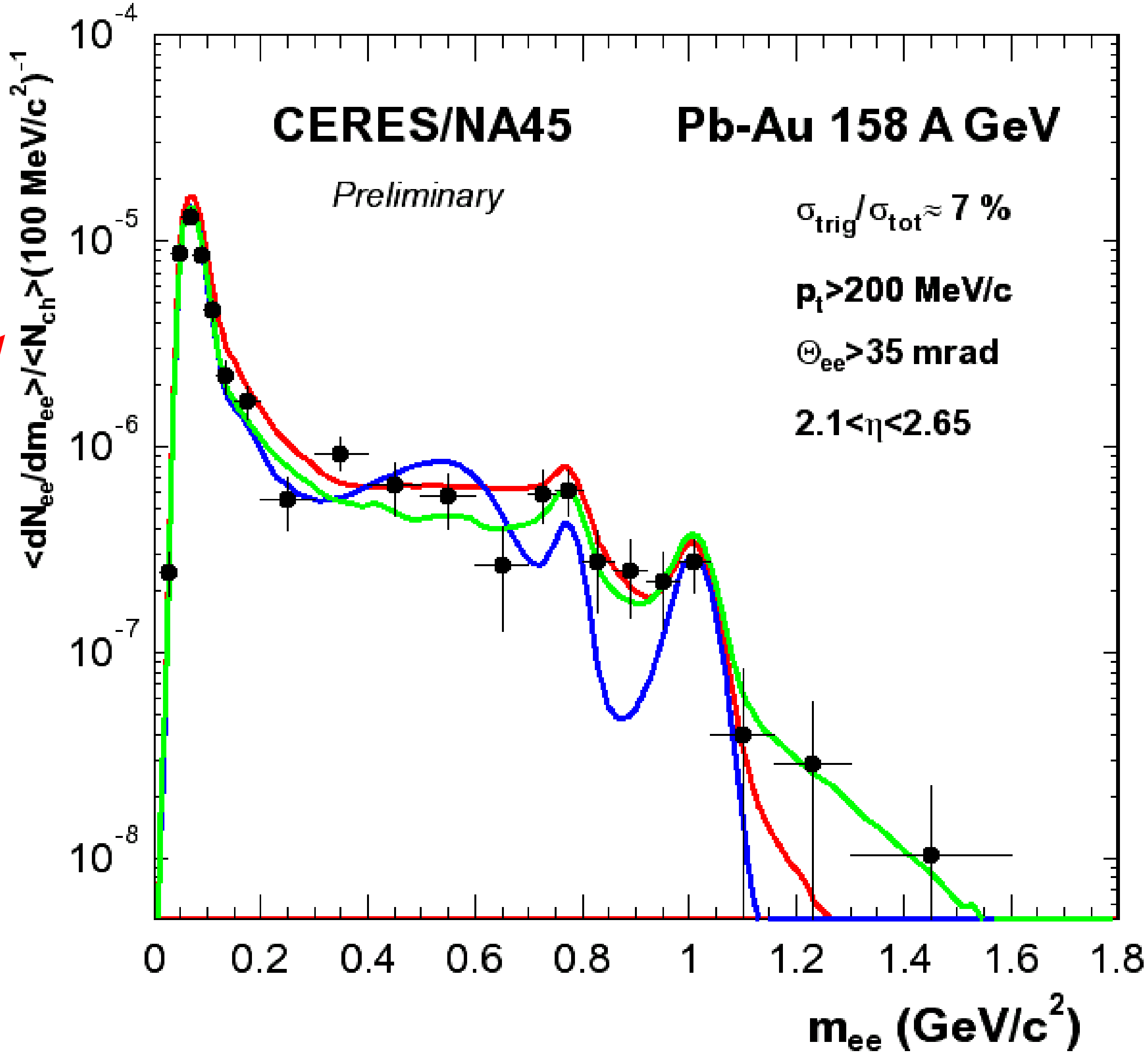
- ***dileptons traditionally normalized to $dN_{ch}/d\eta$***
- ***rather than repeating the standard analysis, for the 2000 data set new approach:***

data driven N_{ch} analysis (no Monte Carlo!)

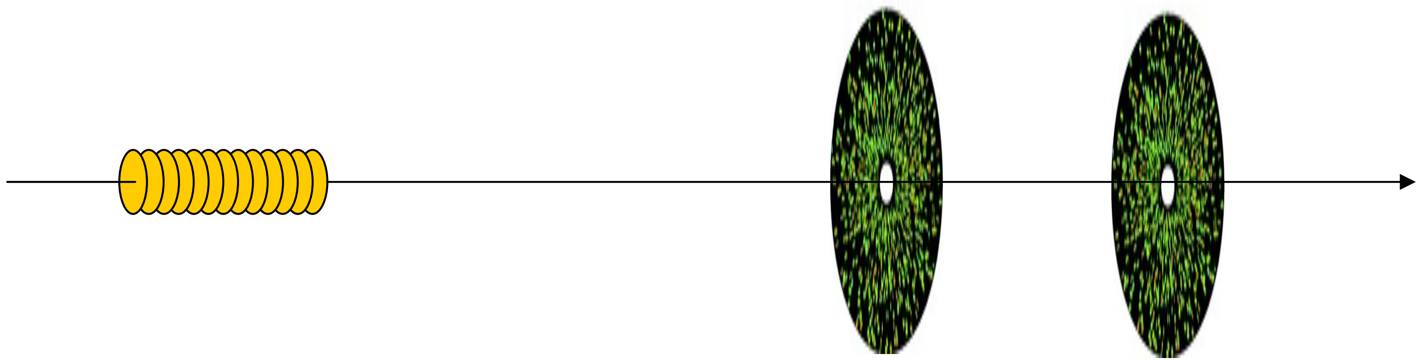
CERES e+e- mass spectrum:

traditionally normalized to N_{ch}

N_{ch} in 2.1<η<2.65



$dN_{ch}/d\eta$ determination without Monte Carlo



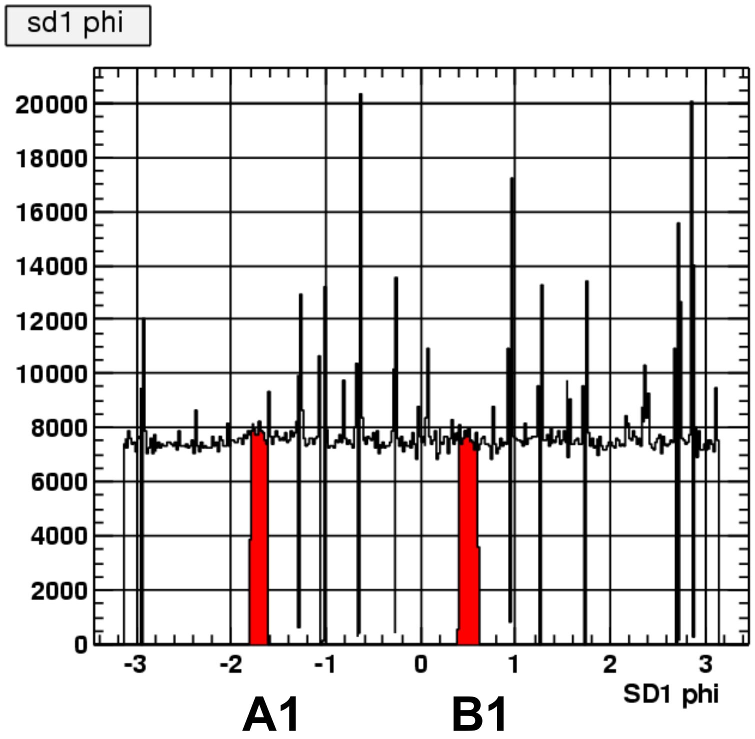
segmented Au target
13 disks 25 μm thick
diameter 0.6 mm
disk-to-disk 2 mm

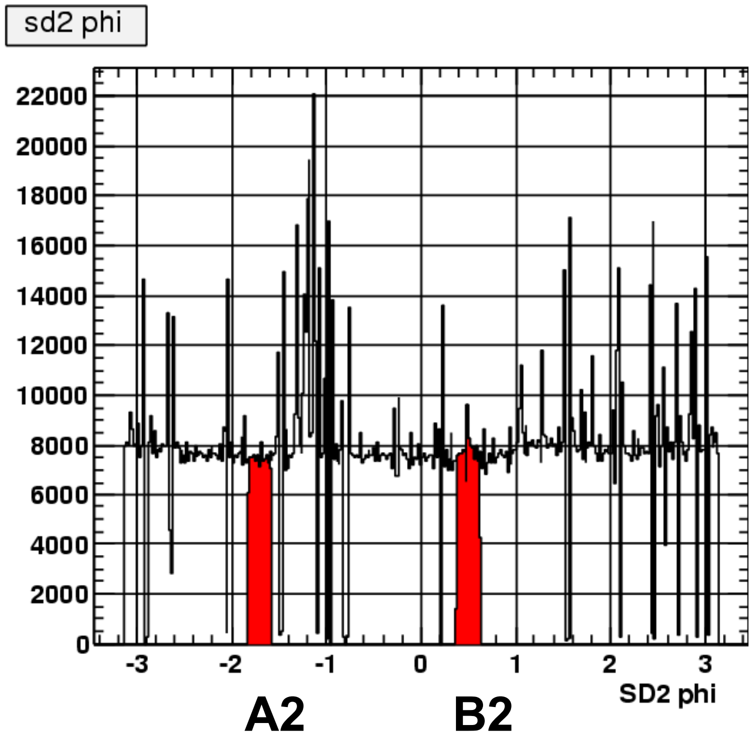
two silicon drift detectors
360 anodes in phi
(hit makes signal on 2-3 anodes)
radius via drift time

in principle can be done by counting tracks, track := matching hits in SD1 and SD2. But…

- ***single track efficiency***
- ***fake tracks***
- ***two-track resolution***
- ***delta electrons***

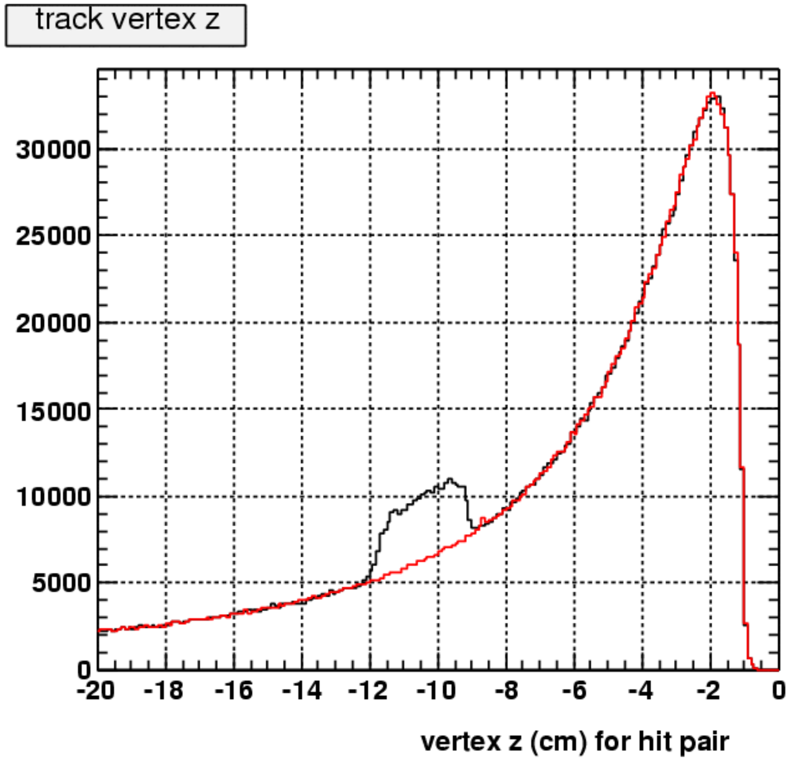
single track efficiency

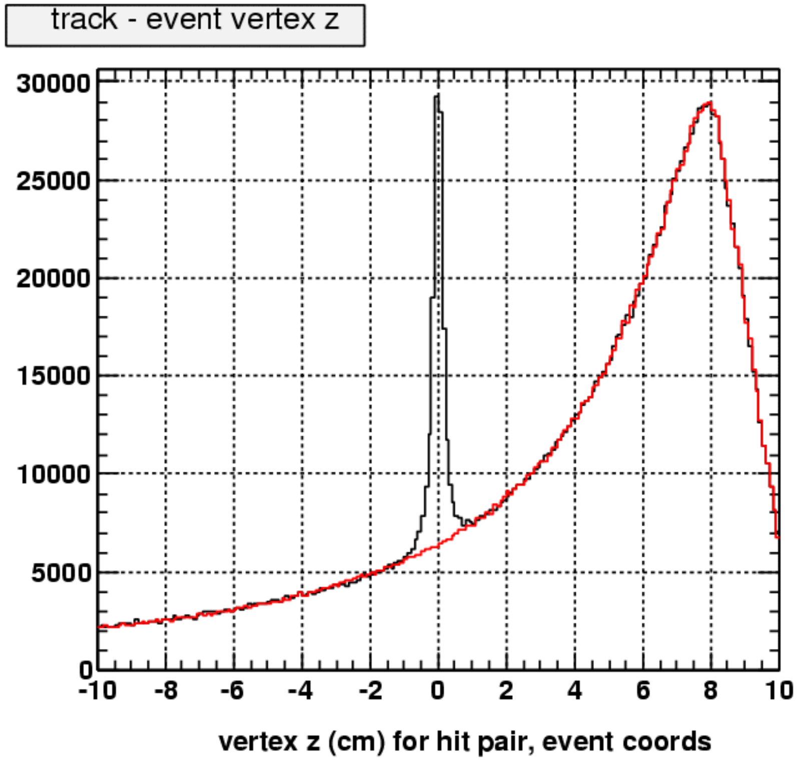




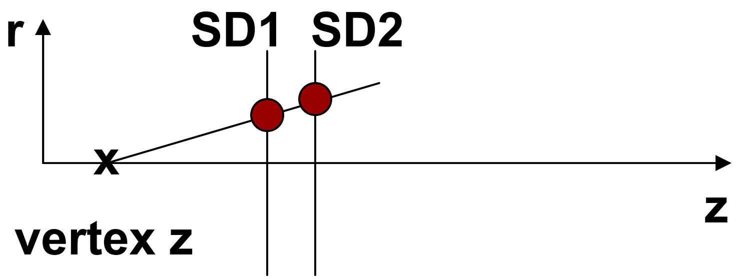
- **pick two regions of phi without dead anodes**
- **acceptance determined by SD1 (narrower windows)**

fake track subtraction





abscissa:

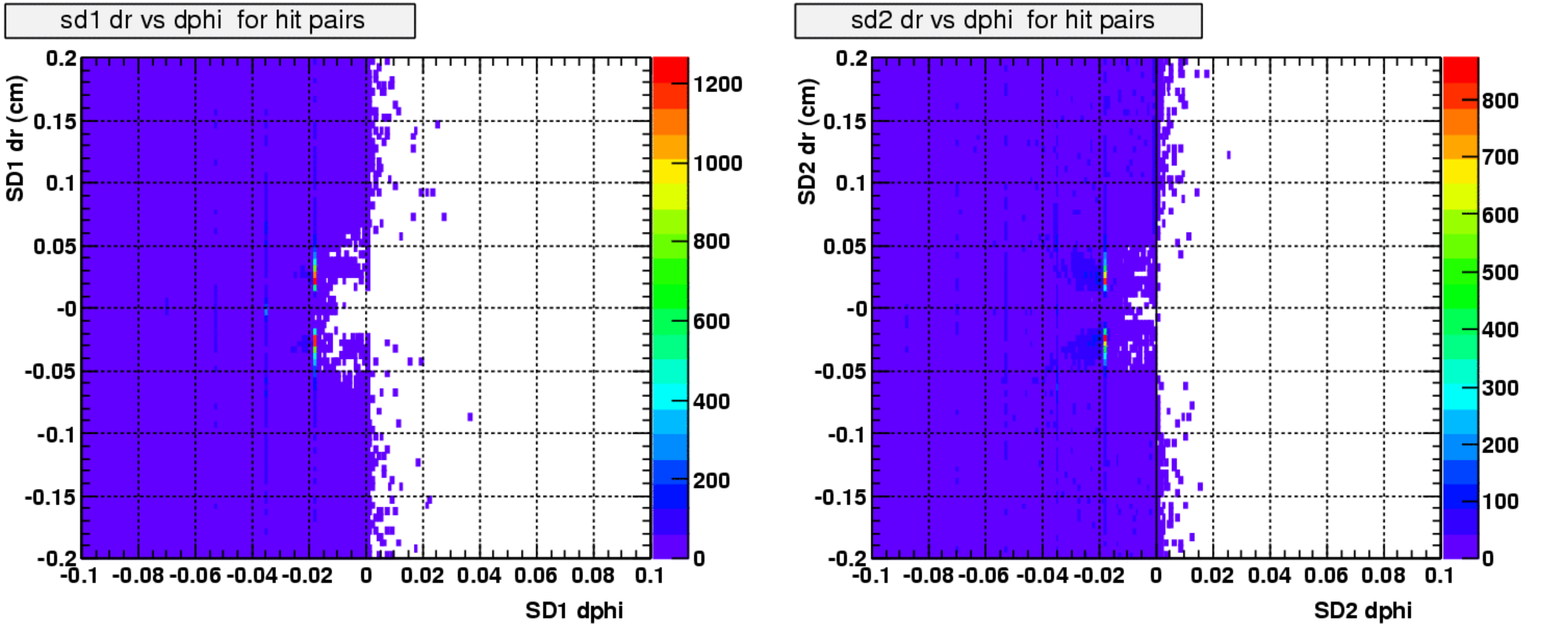


ordinate:

- aligned A1*A2 + B1*B2

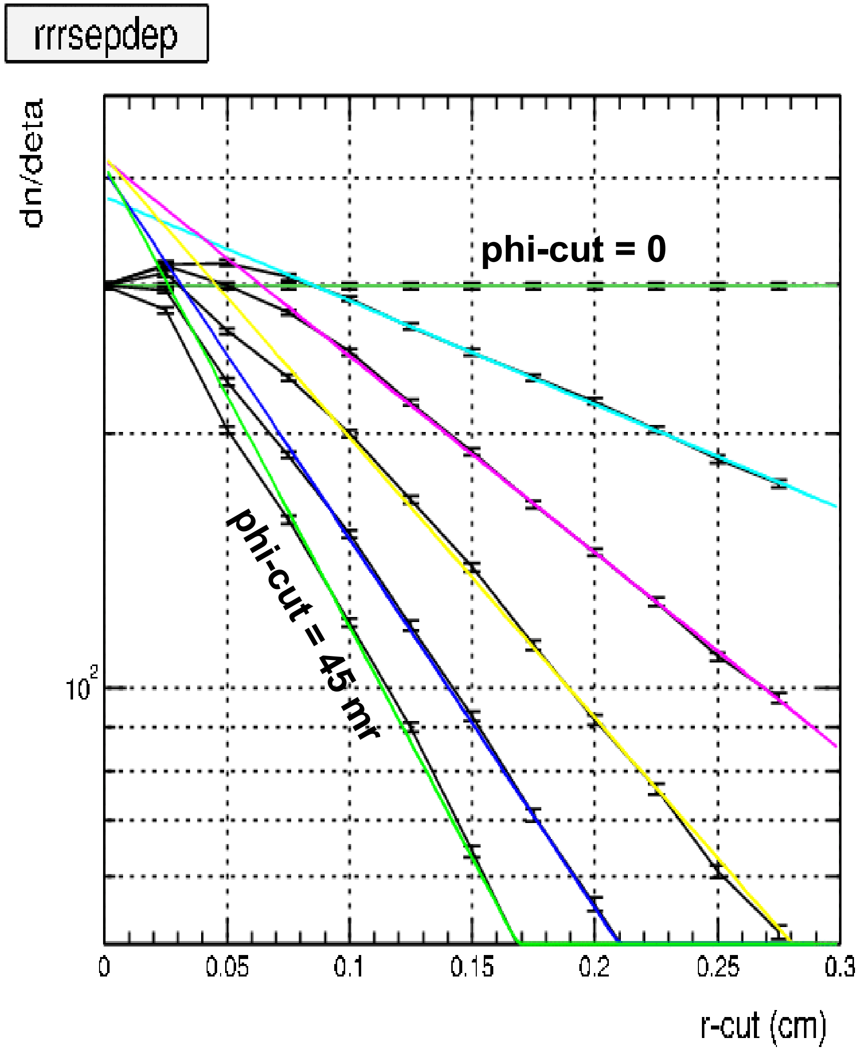
- rotated A1*B2 + B1*A2

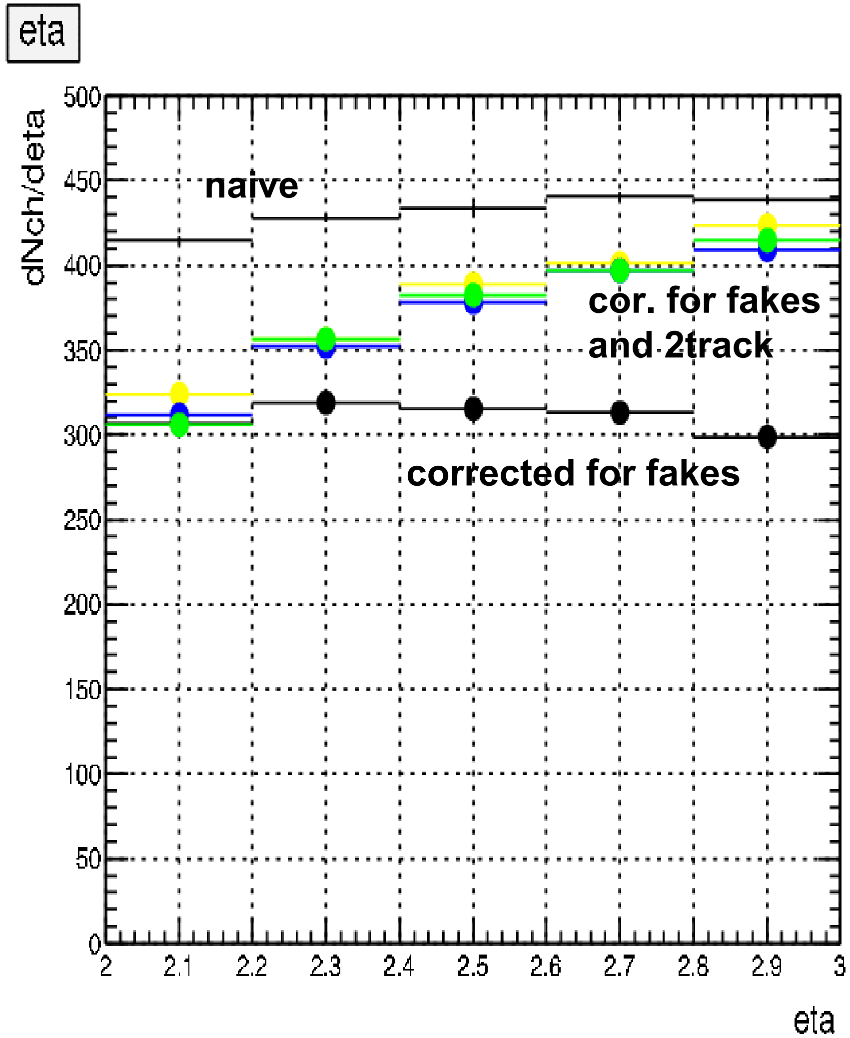
two-track resolution



- inefficiency for pairs of close tracks
- make it worse by applying cuts, study the influence on the result

two-track cuts, extrapolated to zero

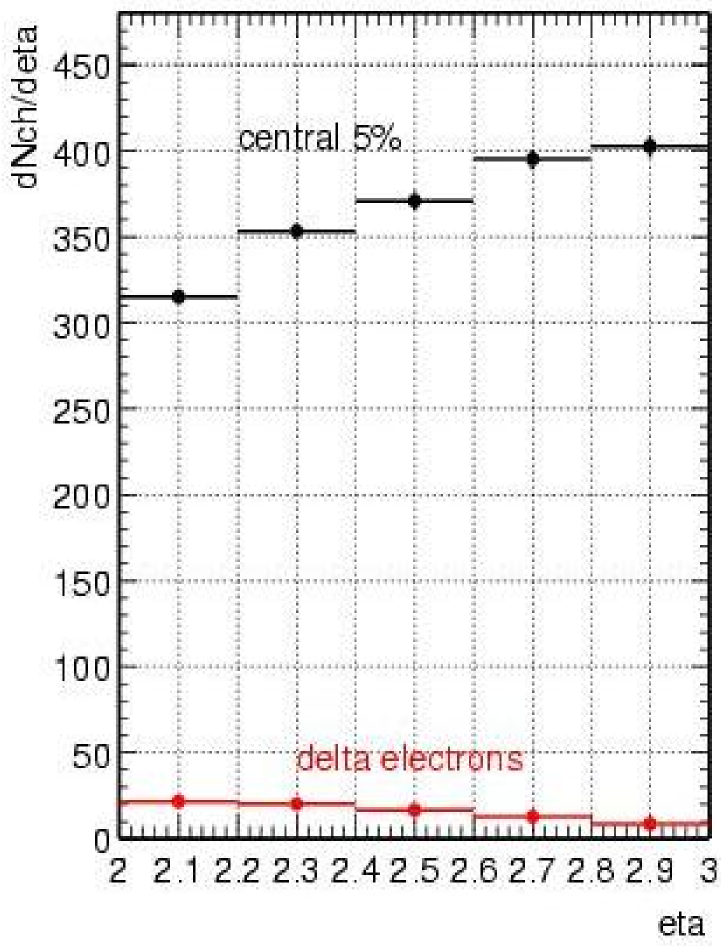




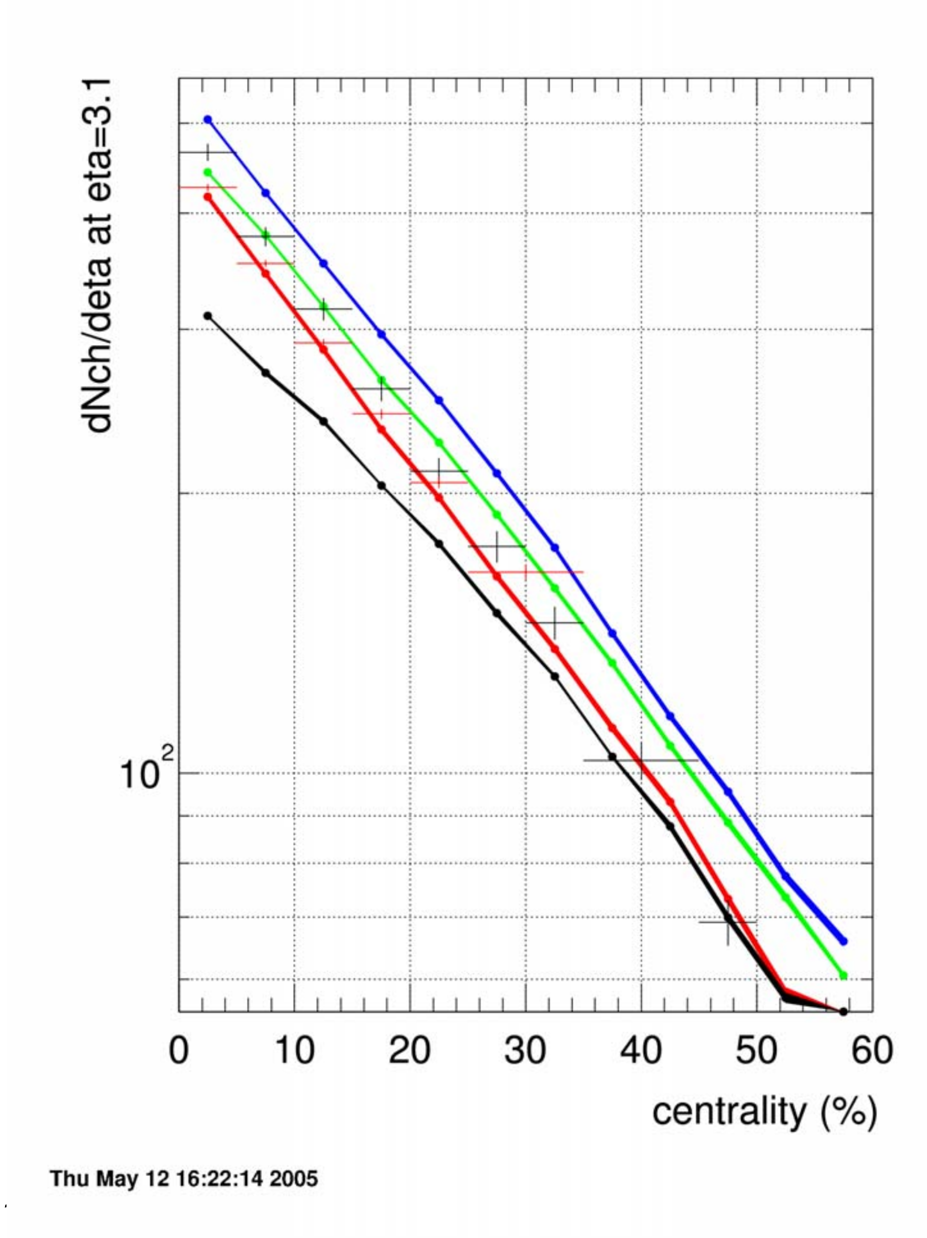
delta electrons

determined in the same way but using data taken with the beam trigger

1/2 of the obtained delta electron multiplicity subtracted (on average, beam passes through half of the target thickness before making an interaction)



$dN_{ch}/d\eta$ vs centrality



raw

corrected for fakes

…and for 2-track resolution

seen by TPC (not discussed here)

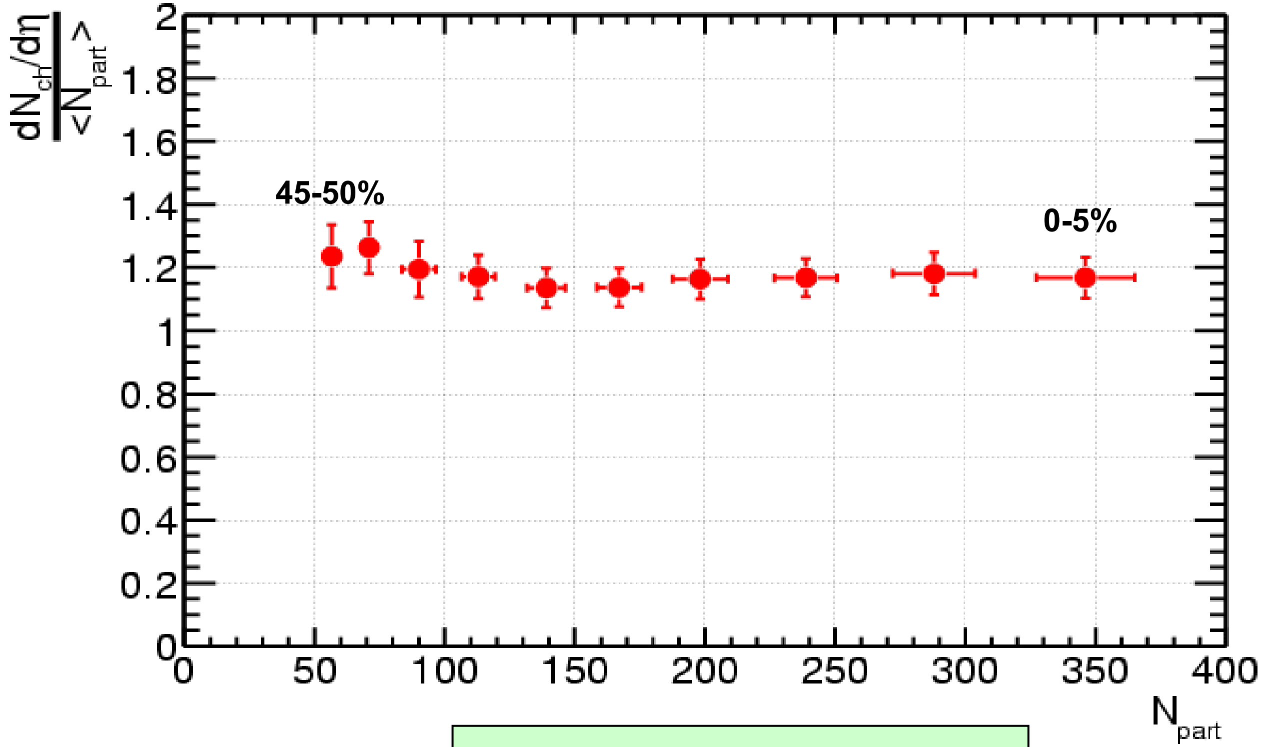
NA57

NA50

corrections are significant

corrected results agree with NA57 and NA50

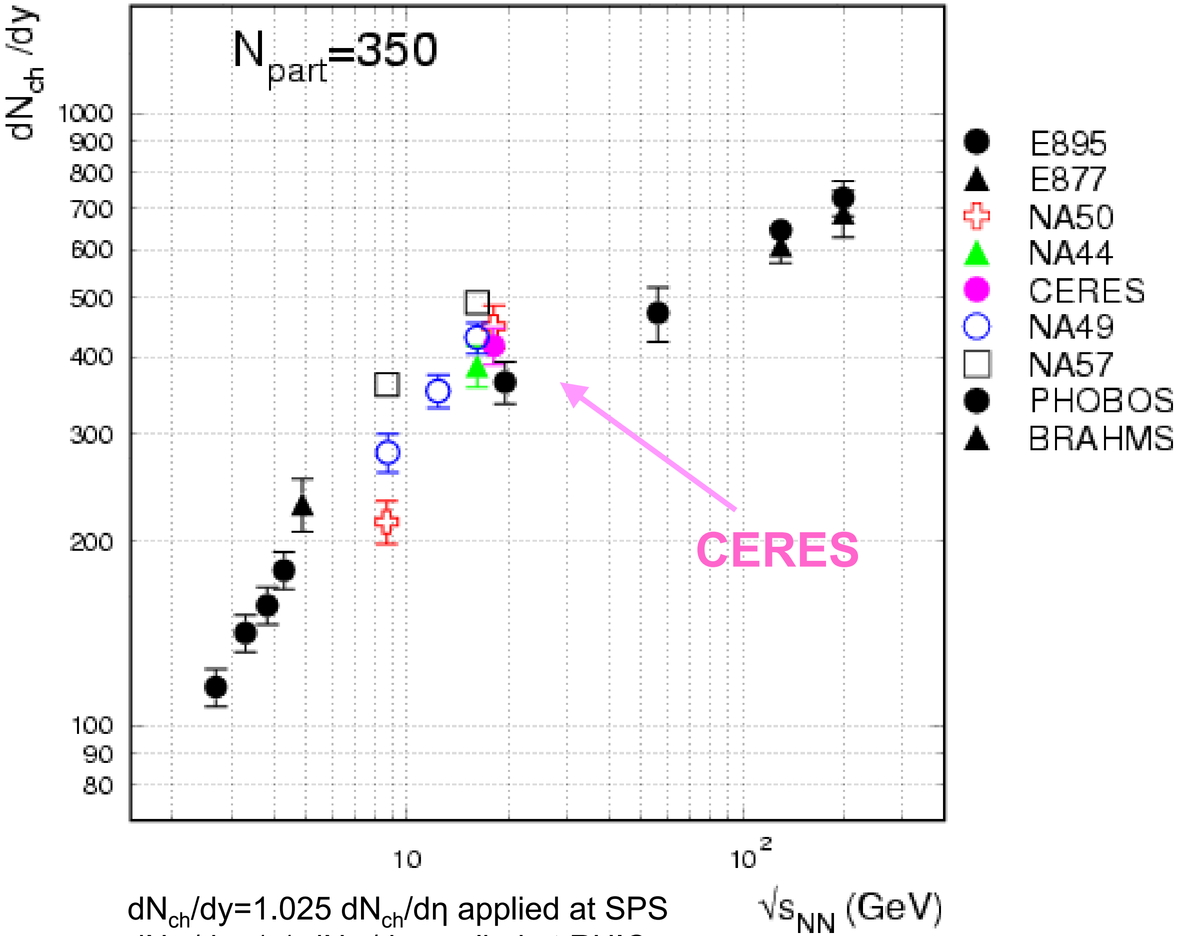
$dN_{ch}/d\eta$ vs centrality



flat N_{ch} per participant

dN_{ch}/dy vs sqrt(s)

dN_{ch}/dy in central collisions of Au or Pb
compilation by Anton Andronic



$dN_{ch}/dy=1.025\ dN_{ch}/d\eta$ applied at SPS
$dN_{ch}/dy=1.1\ dN_{ch}/d\eta$ applied at RHIC

good agreement with NA49, NA50, and NA44

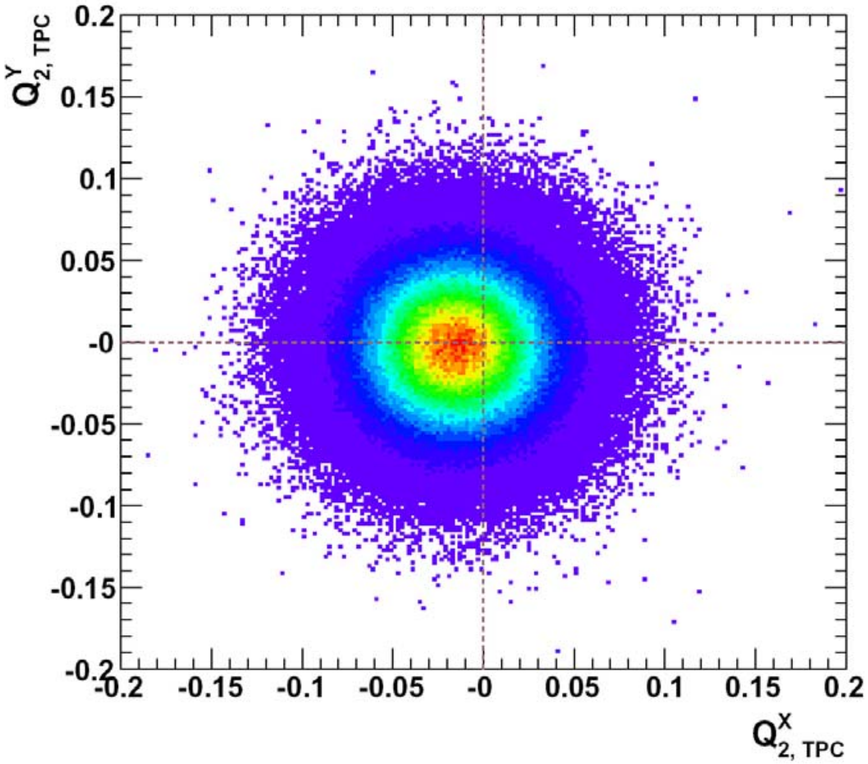
dNch/dη: problems and solutions

- *single track efficiency*
  use the best performing parts of detectors
- *fake tracks*
  subtract event mixing
- *two-track resolution*
  apply separation cuts and extrapolate to zero
- *delta electrons*
  measure and subtract

absolute multiplicities without Monte Carlo

- **absolute multiplicities without Monte Carlo**
- **result very reasonable**
- **systematic error estimate 12% max**

determination of the reaction plane



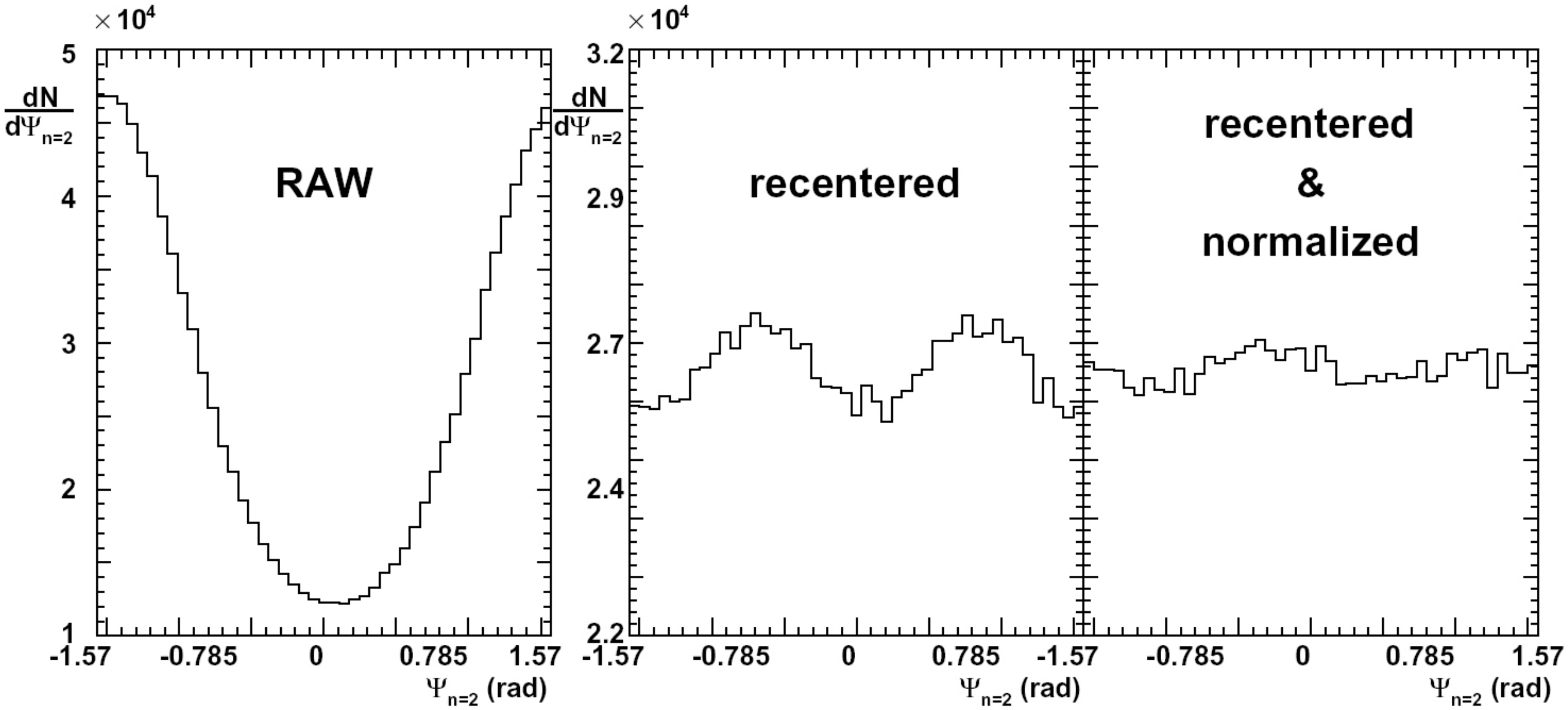
$$Q_2^X = \sum_i p_t \cdot \cos(2\varphi_i)$$

$$Q_2^Y = \sum_i p_t \cdot \sin(2\varphi_i)$$

$$\Phi_{RP} = \frac{1}{2}\arctan\left(\frac{Y_2}{X_2}\right)$$

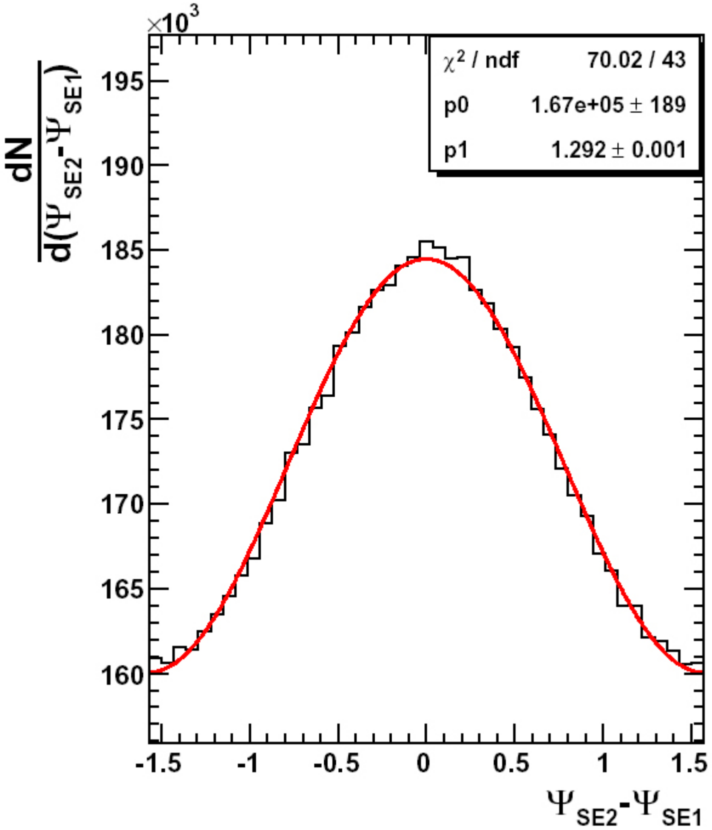
distribution of the reaction plane angle

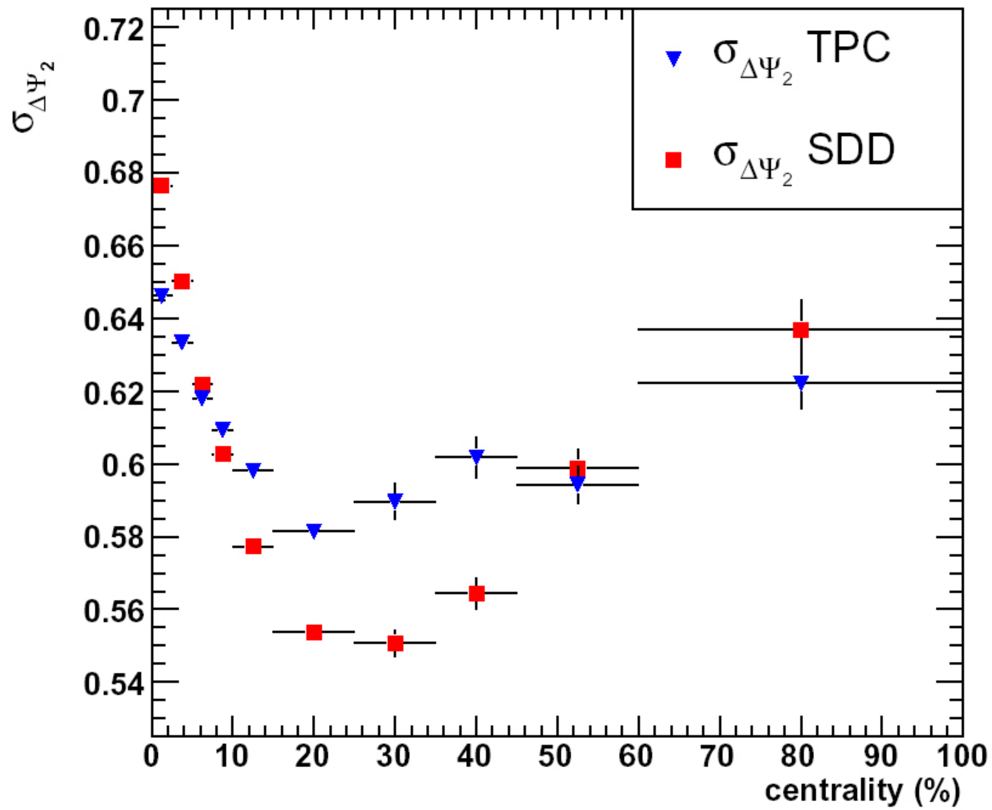
D. Antonczyk



resolution of the reaction plane

D. Antonczyk





resolution 31°-38° (depending on centrality)

e^+e^- analysis

tracking

↓

electron identification

↓

π^0-Dalitz and γ-conversion rejection

↓

pairing

↓

subtraction of background
(like-sign or mixed events)

↓

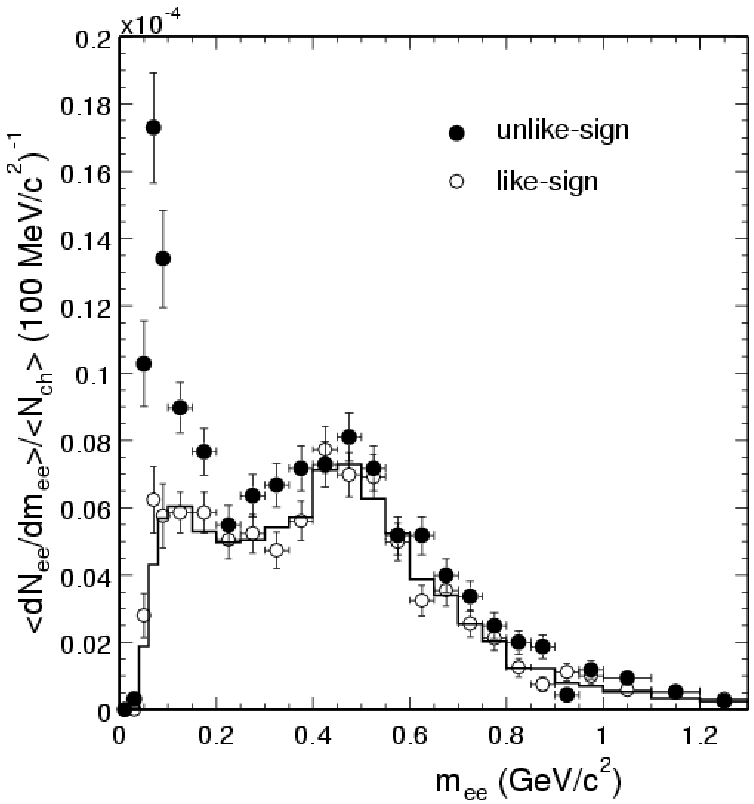
efficiency correction

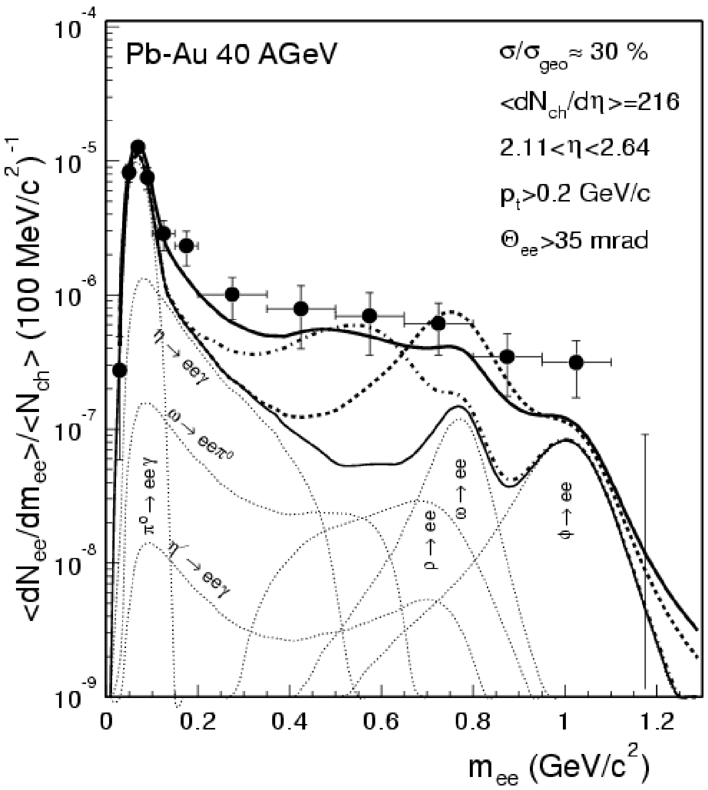
↓

mass spectrum

e+e- in Pb+Au at 40 GeV per nucleon

Kirill Filimonov, Sanja Damjanovic
Phys. Rev. Lett. 91 (2003) 042301

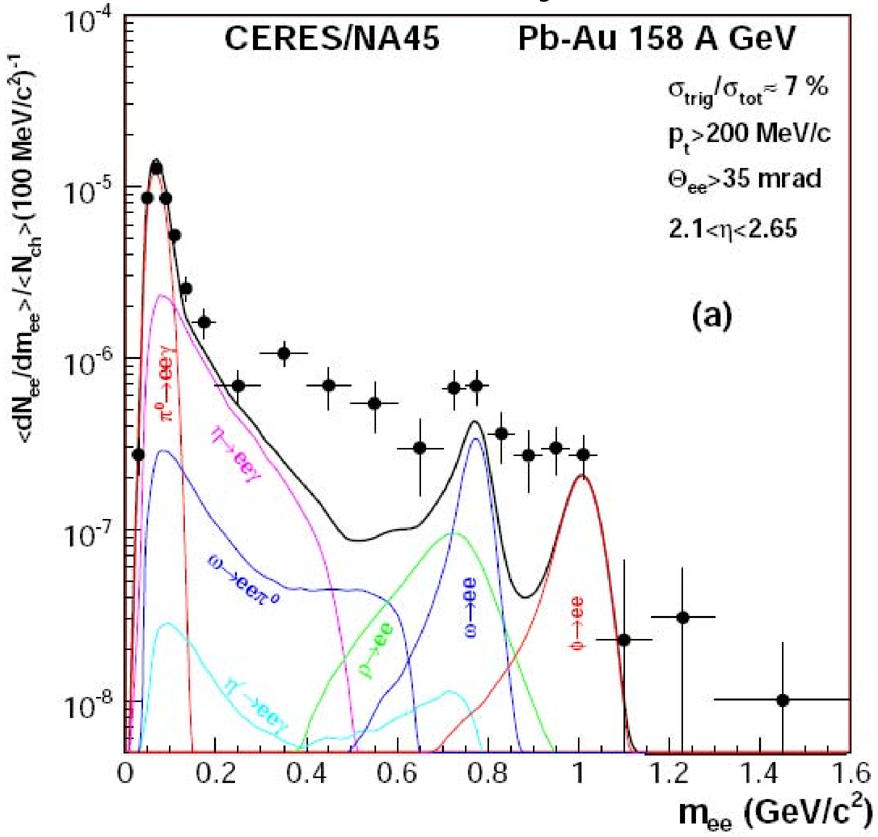




Modification of the ρ-meson mass observed in central Pb-Au Collisions at CERN SPS

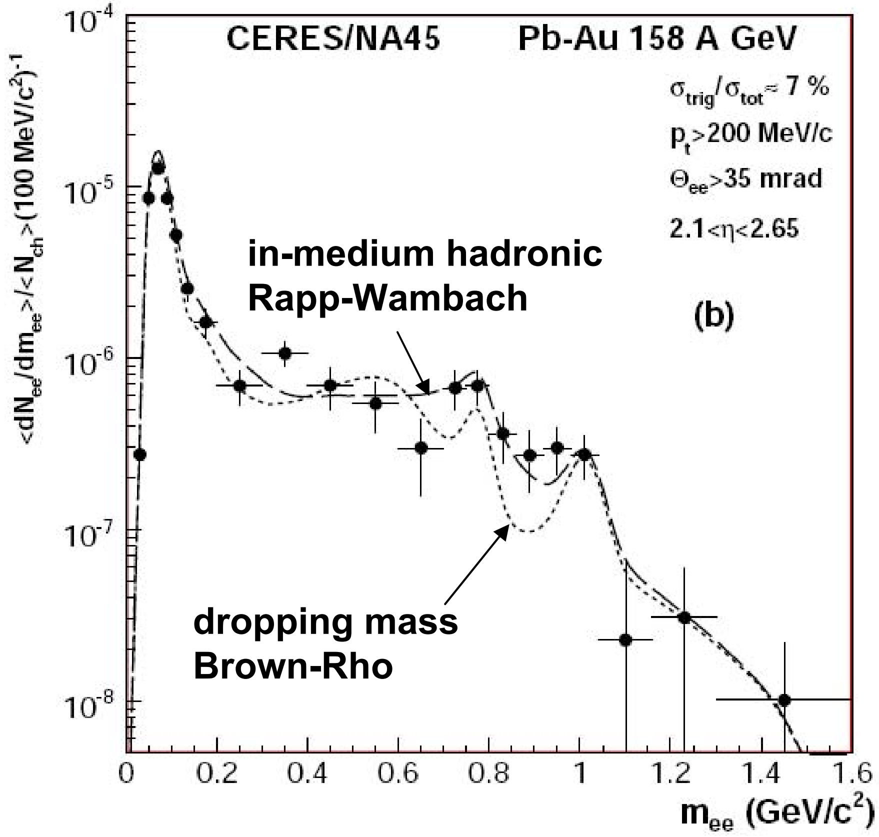
CERES, submitted to Phys. Lett. B

compared to the cocktail of e+e- from hadron decays → excess

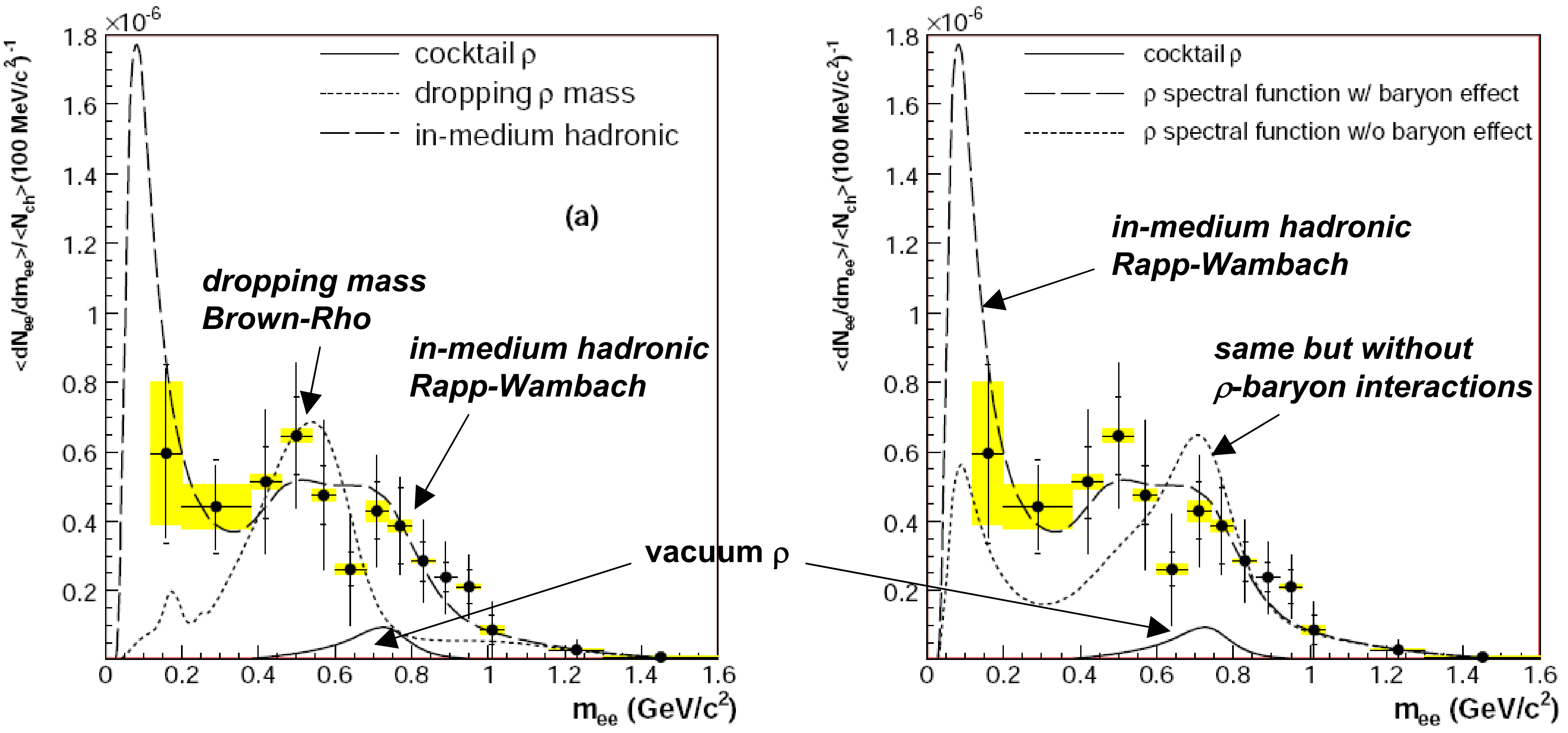


2818±348 open pairs
S/B = 1/21
enh. 2.58±0.32(stat)±0.41(syst)±0.77(cock)

compared to two model calculations → "in-medium hadronic" scenario fits better



closer look: ρ-meson signal (all other cocktail components subtracted)



Brown, Rho, PRL 66(1991)2720, Phys. Rep. 269(1996)333, Phys. Rep. 363(2002)85
Rapp, Wambach, Adv.Nucl.Phys. 25(2000)1, Hess,Rapp, PRL 97(2006)162302

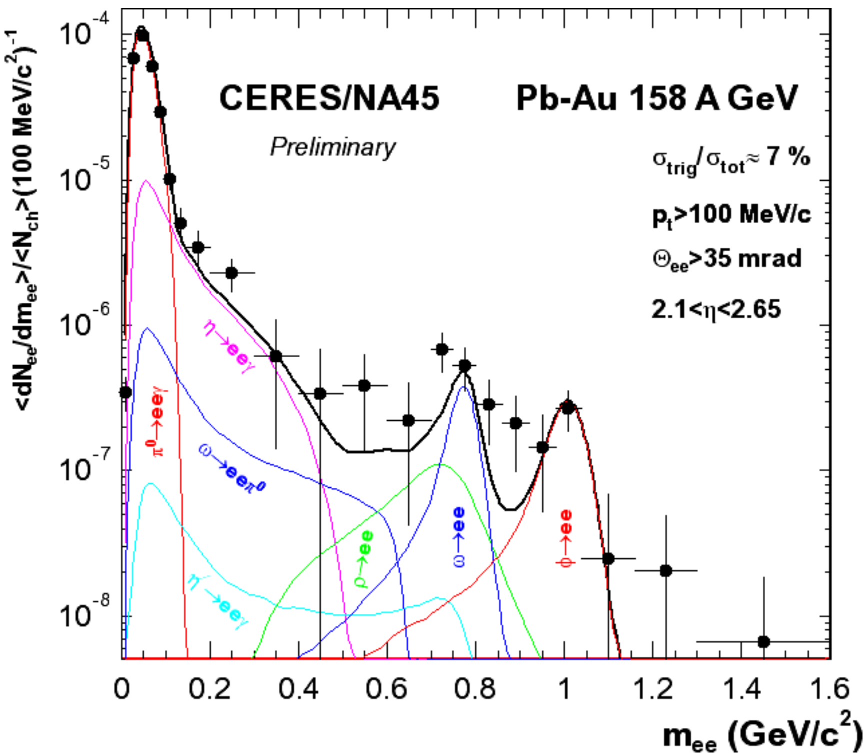
ρ - enhancement in hot and dense medium

interactions with baryons responsible for the observed ρ-meson modification

e+e- mass spectrum: lowering the pt-cut

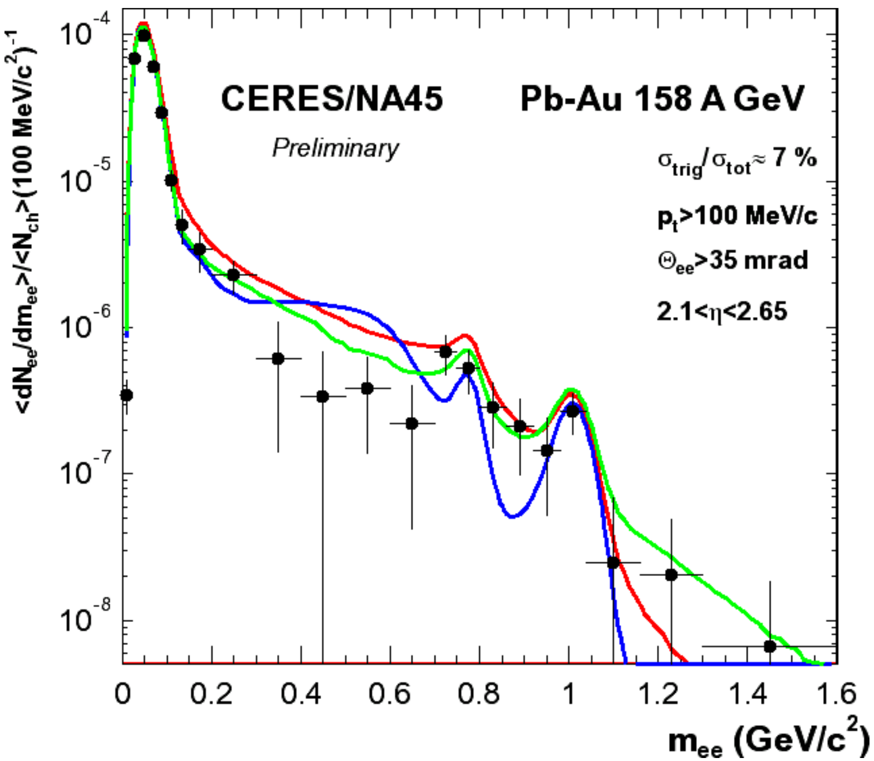
Pb+Au at 158 GeV per nucleon

Sergey Yurevich



S/B = 1/87

enhancement for 0.2<m<0.6: 1.52 ± 0.36

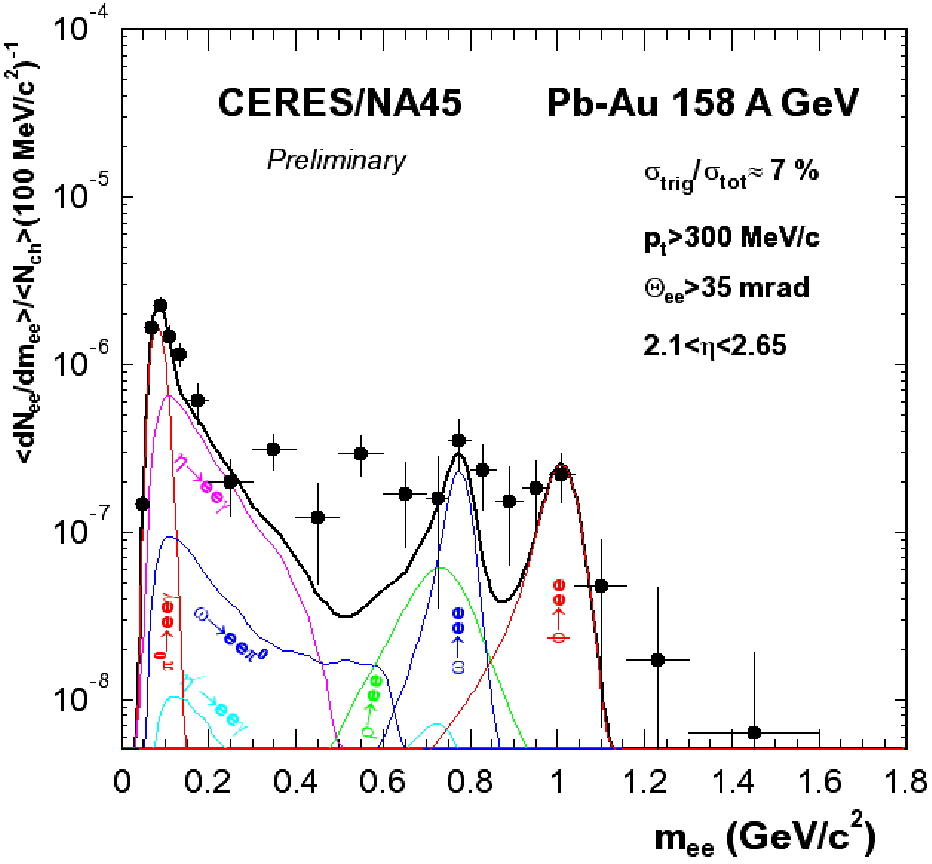


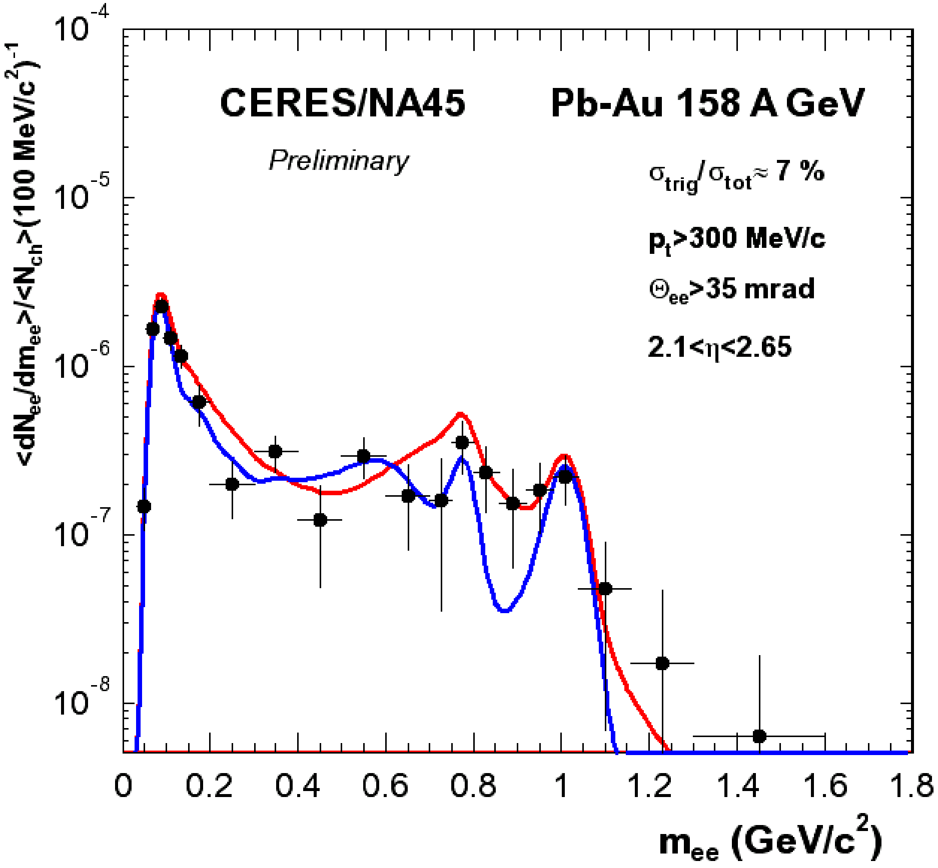
poor signal-to-background ratio due to the π^0-Dalitz electrons

e+e- mass spectrum: increasing the pt-cut

Pb+Au at 158 GeV per nucleon

Sergey Yurevich



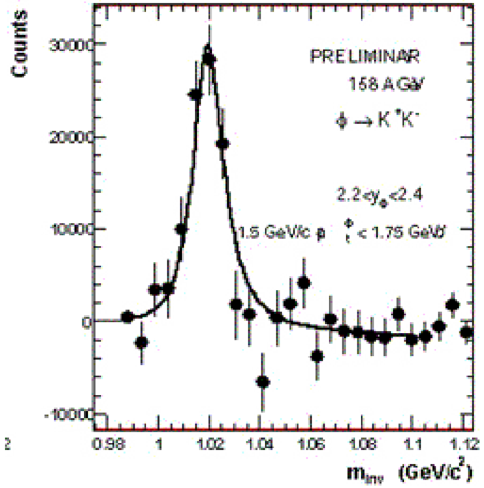


ϕ puzzle

$\phi \rightarrow e^+e^-$ extracted from the e^+e^- mass spectrum;

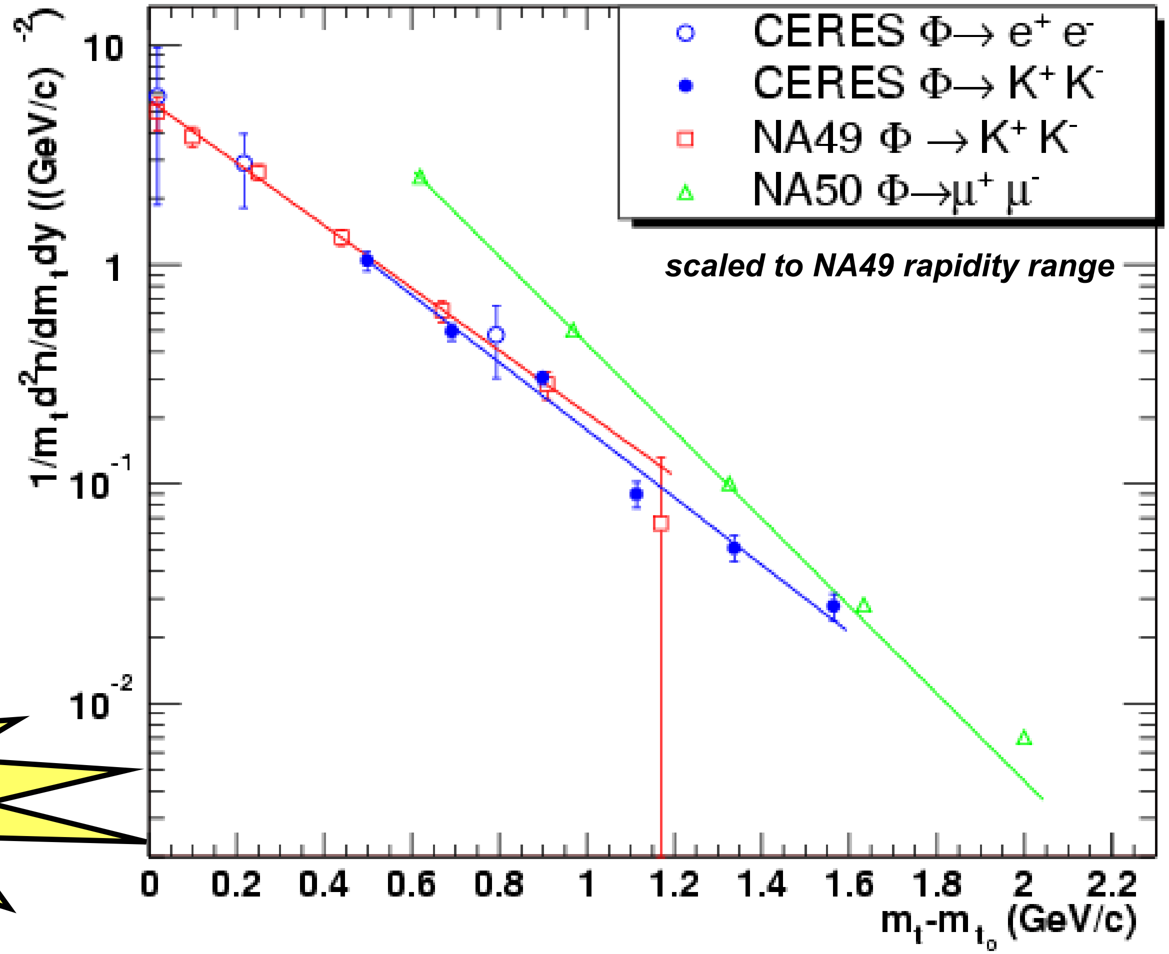
ϕ puzzle: D. Röhrich, J.Phys.G 27(2001)355

$\phi \rightarrow K^+K^-$



Phys. Rev. Lett. 96 (2006) 152301

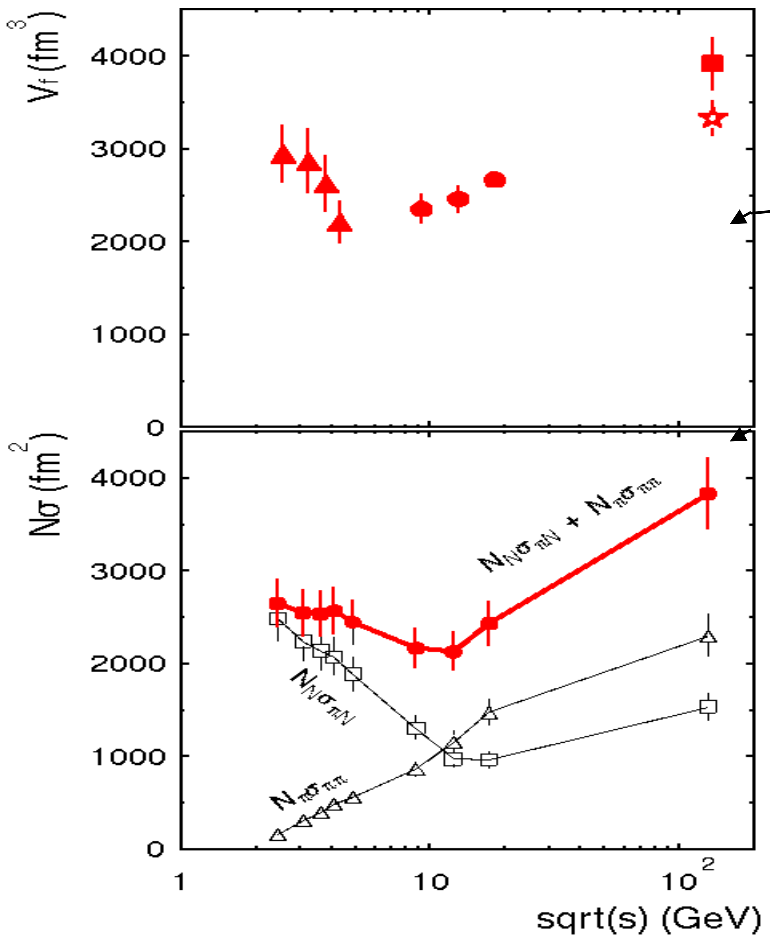
Ana Marin



leptonic and hadronic channels agree

First HBT analysis with upgraded CERES

Heinz Tilsner and Harry Appelshäuser, PRL 90 (2003) 022301



Freeze-out volume
$V_f = (2\pi)^{3/2} R_{long} R_{side}^2$
has a minimum at a beam energy of 10-40 GeV per nucleon

Particle multiplicity times mean hadron-hadron cross-section Nσ has a similar beam energy dependence

V_f / Nσ = λ_f = 1 fm
independent of beam energy

freeze-out when
mean free path = 1 fm

new analysis by D. Antończyk 2003-2006

- ***better momentum, centrality, reaction plane resolutions***
- ***better two-track separation cut***
- ***full statistics (30 M events)***
- ***emphasis on nonidentical and reaction plane dependence…***

…however, most of the statistics central 7%

pion-pion correlation function

correlation function
= pair distribution,
normalized to event mixing

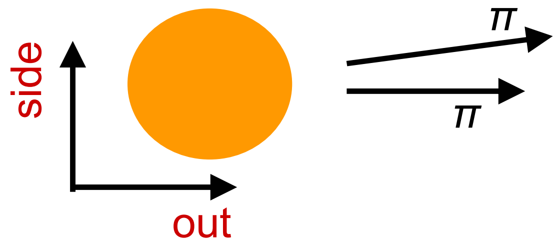
$$C_2(\mathbf{P},\mathbf{q}) = \frac{n(\mathbf{p}_1,\mathbf{p}_2)}{n(\mathbf{p}_1)\, n(\mathbf{p}_2)}$$

with mean momentum $\mathbf{P} = (\mathbf{p}_1 + \mathbf{p}_2)\,/\,2$

and momentum difference $\mathbf{q} = \mathbf{p}_2 - \mathbf{p}_1$

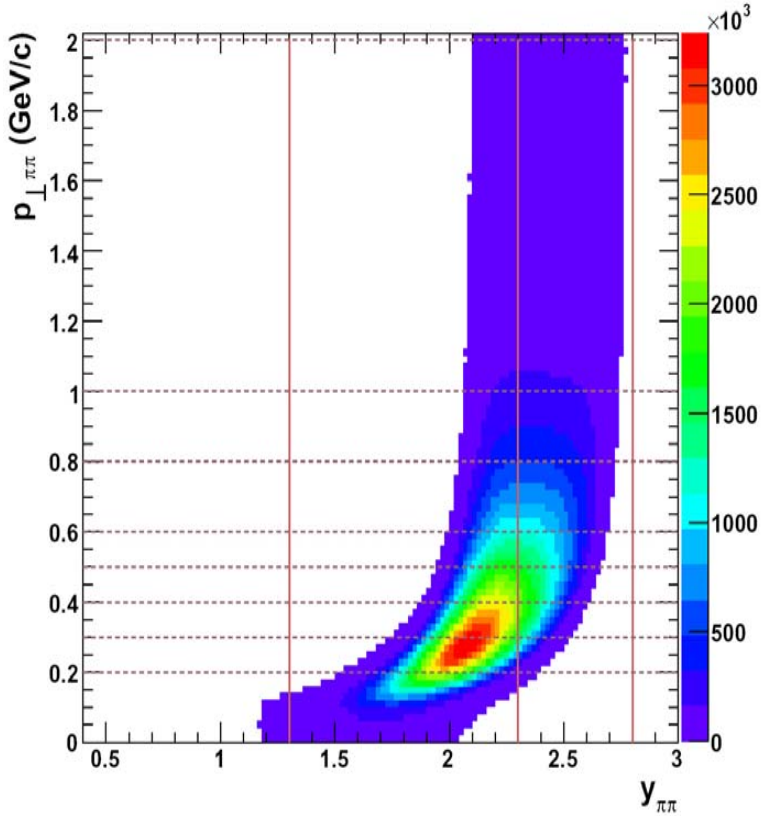
Bertsch-Pratt coordinates
LCMS frame

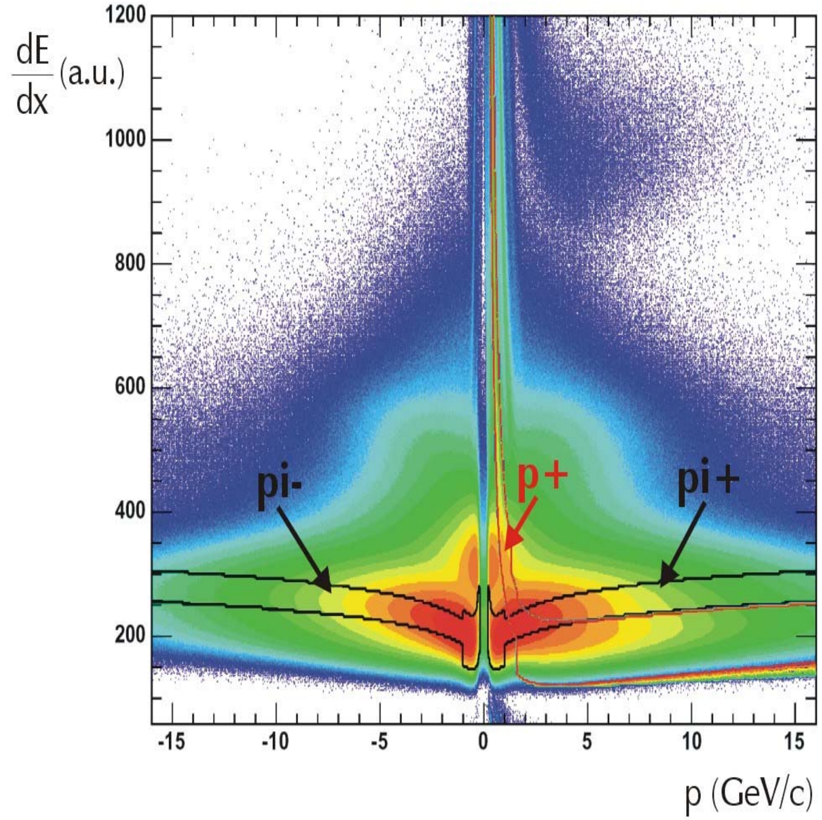
$\mathbf{q} = (q_{out}, q_{side}, q_{long})$



acceptance and particle id

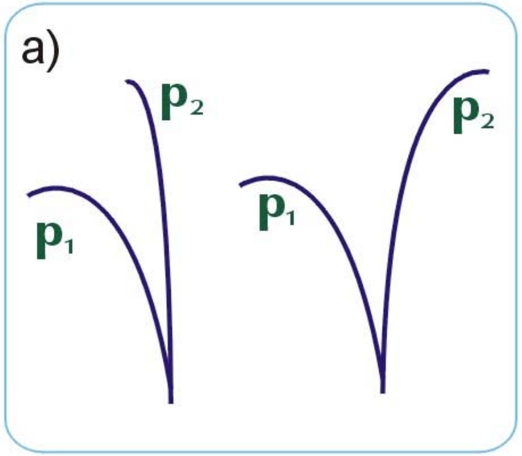
Pb+Au at 158 AGeV

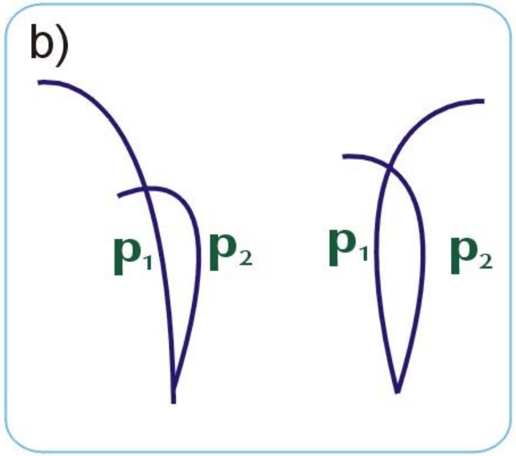


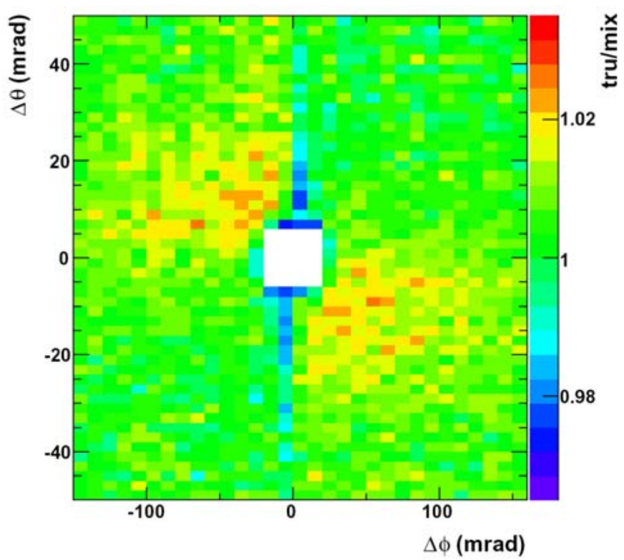


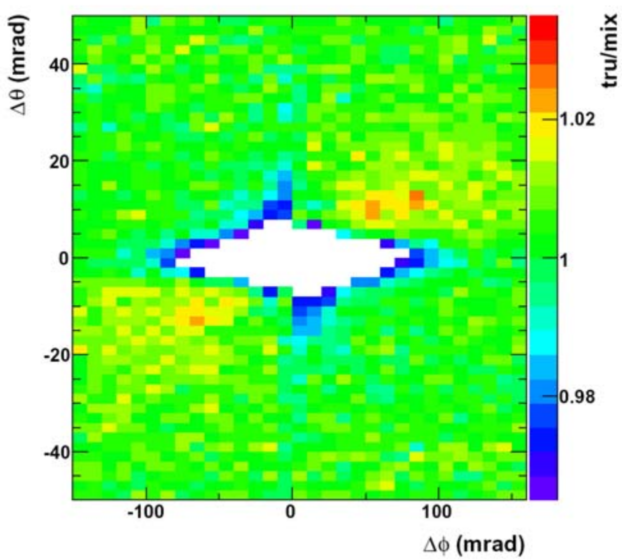
midrapidity: y=2.91

two-track cut





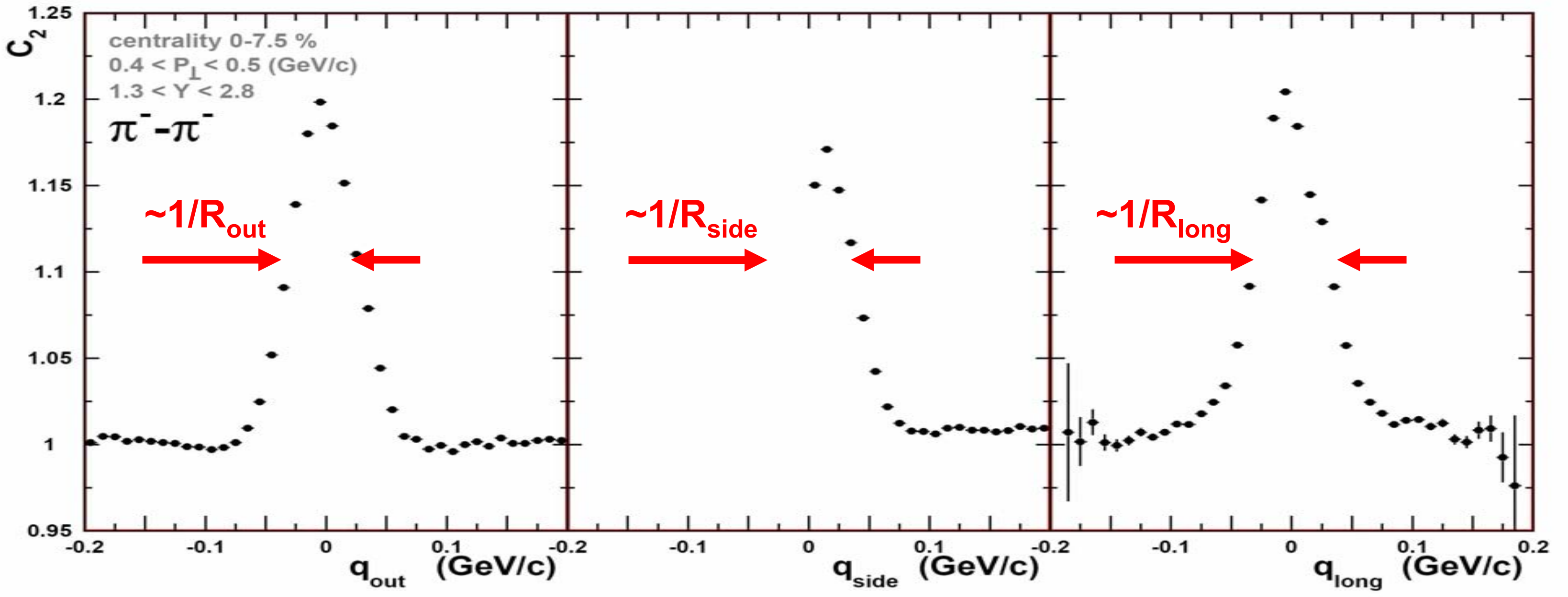




different cuts needed for cowboy and sailor

two-pion correlation function

Pb+Au at 158 AGeV *D. Antonczyk*



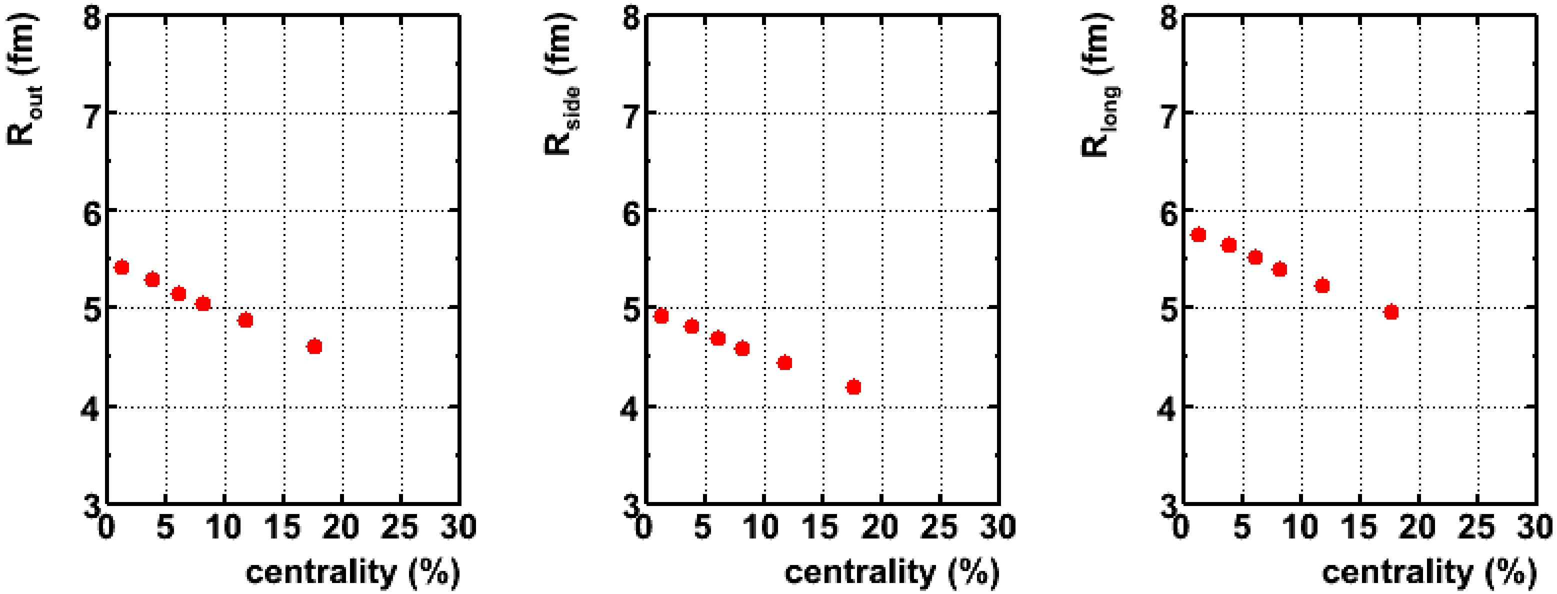
fit with $$C_2(q) = 1 + \lambda \exp\left\{\sum_{i,j} R_{i,j}^2 q_i q_j\right\}$$ *with i,j = out, side, long*

correct for Coulomb and finite momentum resolution

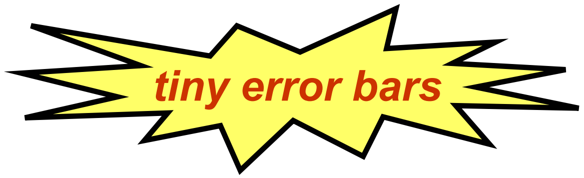
HBT radii: centrality dependence

Pb+Au at 158 AGeV
$< p_t > = 0.47$ GeV/c

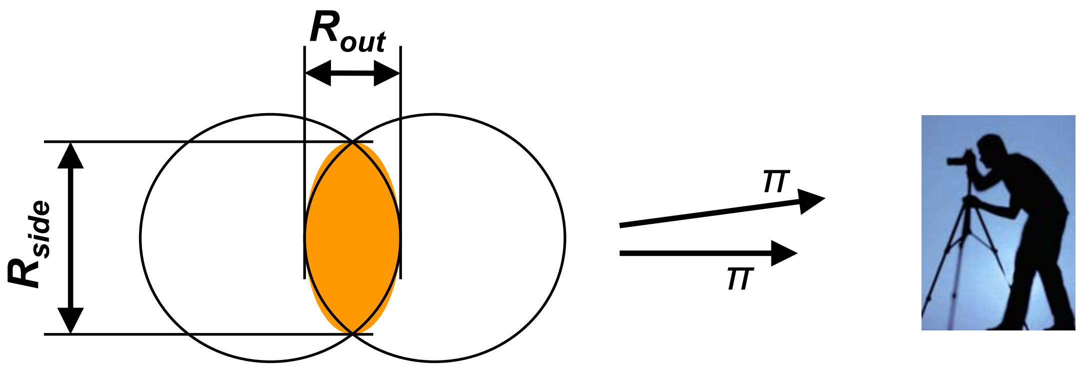
D. Antonczyk



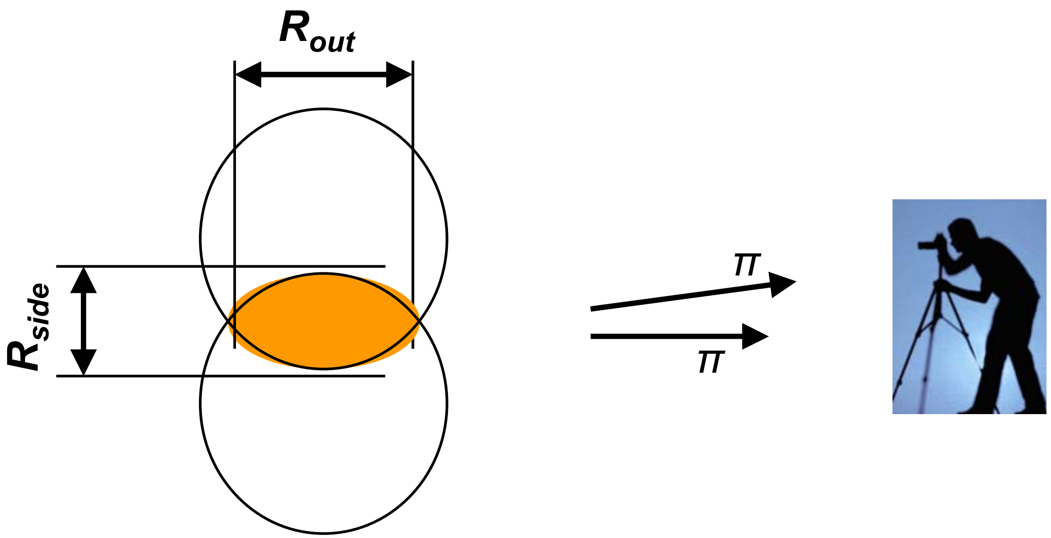
centrality is defined as σ/σ_{GEOM}
with σ_{GEOM} = 6.94 b



HBT radii vs azimuthal pion angle - expectation

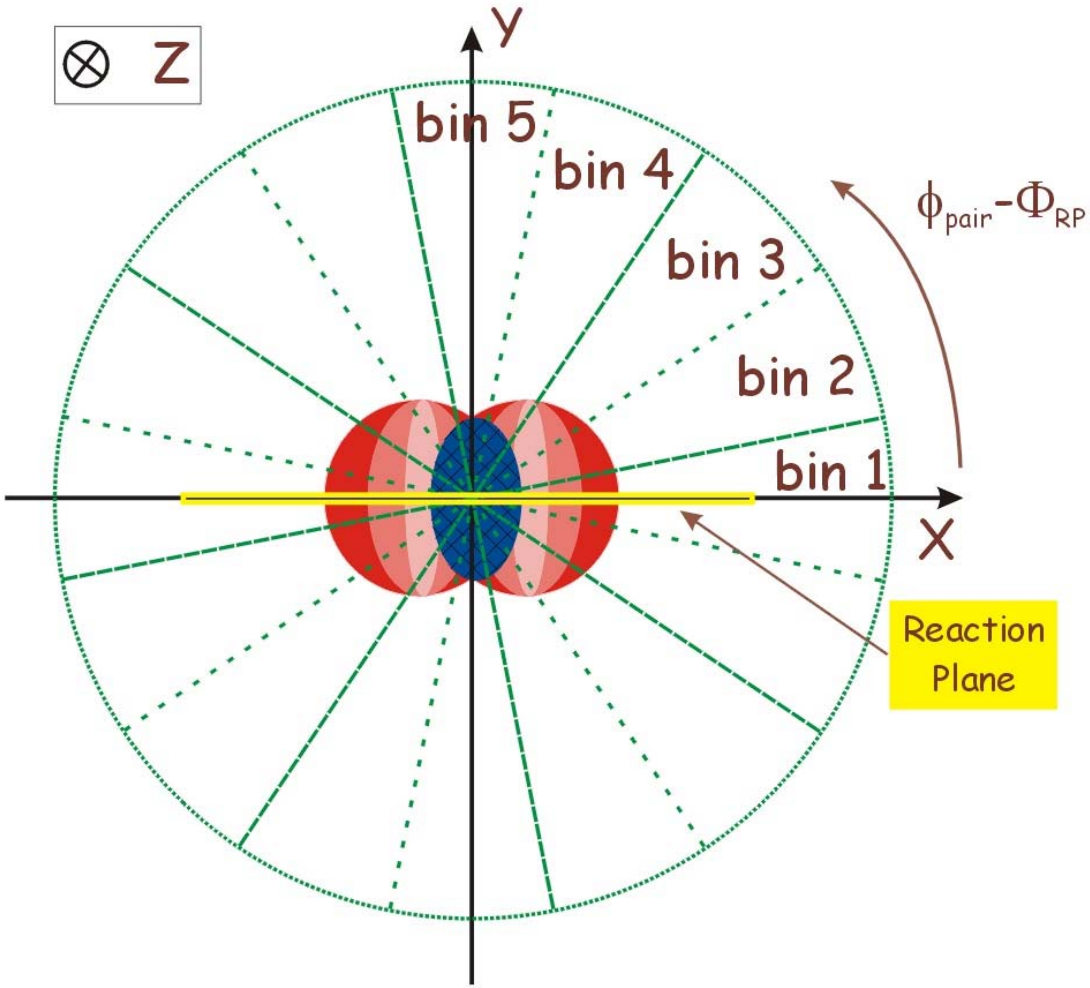


in-plane

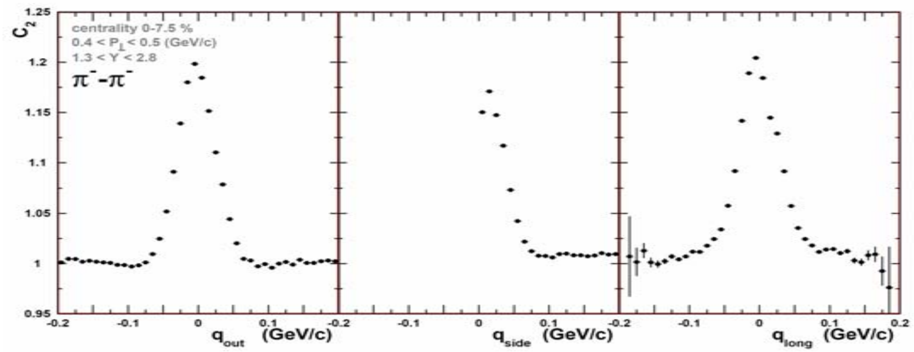


out-of-plane

HBT radii in bins of the azimuthal pair angle



pion-pion correlation function



3-dimensional fit to C_2 performed
R_{out}, R_{side}, R_{long}, R_{ol}, R_{os}, R_{sl} extracted } *separately in each Φ-bin*

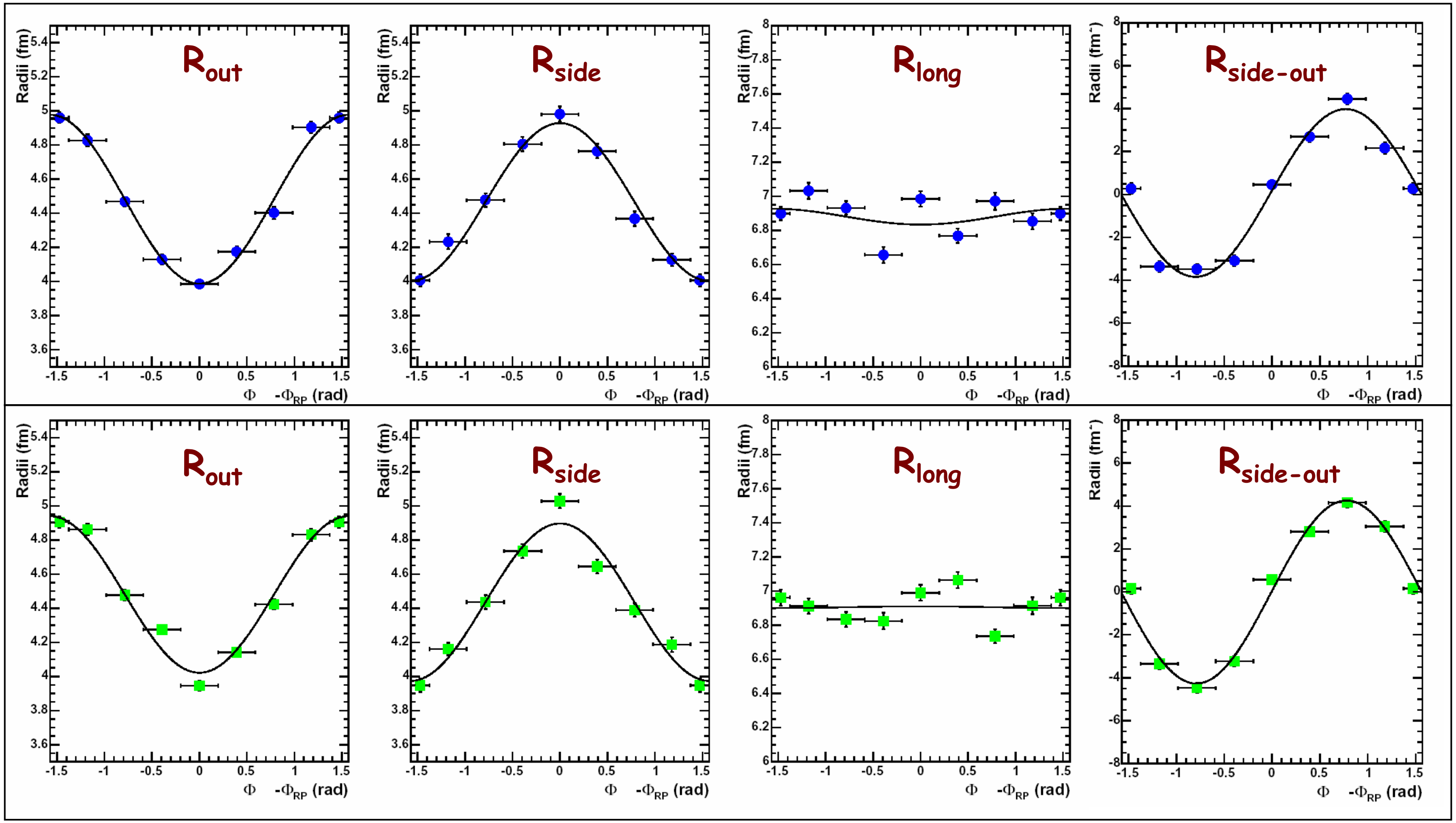
$\boldsymbol{\Phi = \Phi_{\pi\pi} - \Phi_{RP}}$
azimuthal pair angle with respect to the RP

azimuthal angle dependence of the HBT radii - simulation

D. Antonczyk

- $\pi^-\pi^-$
- $\pi^+\pi^+$

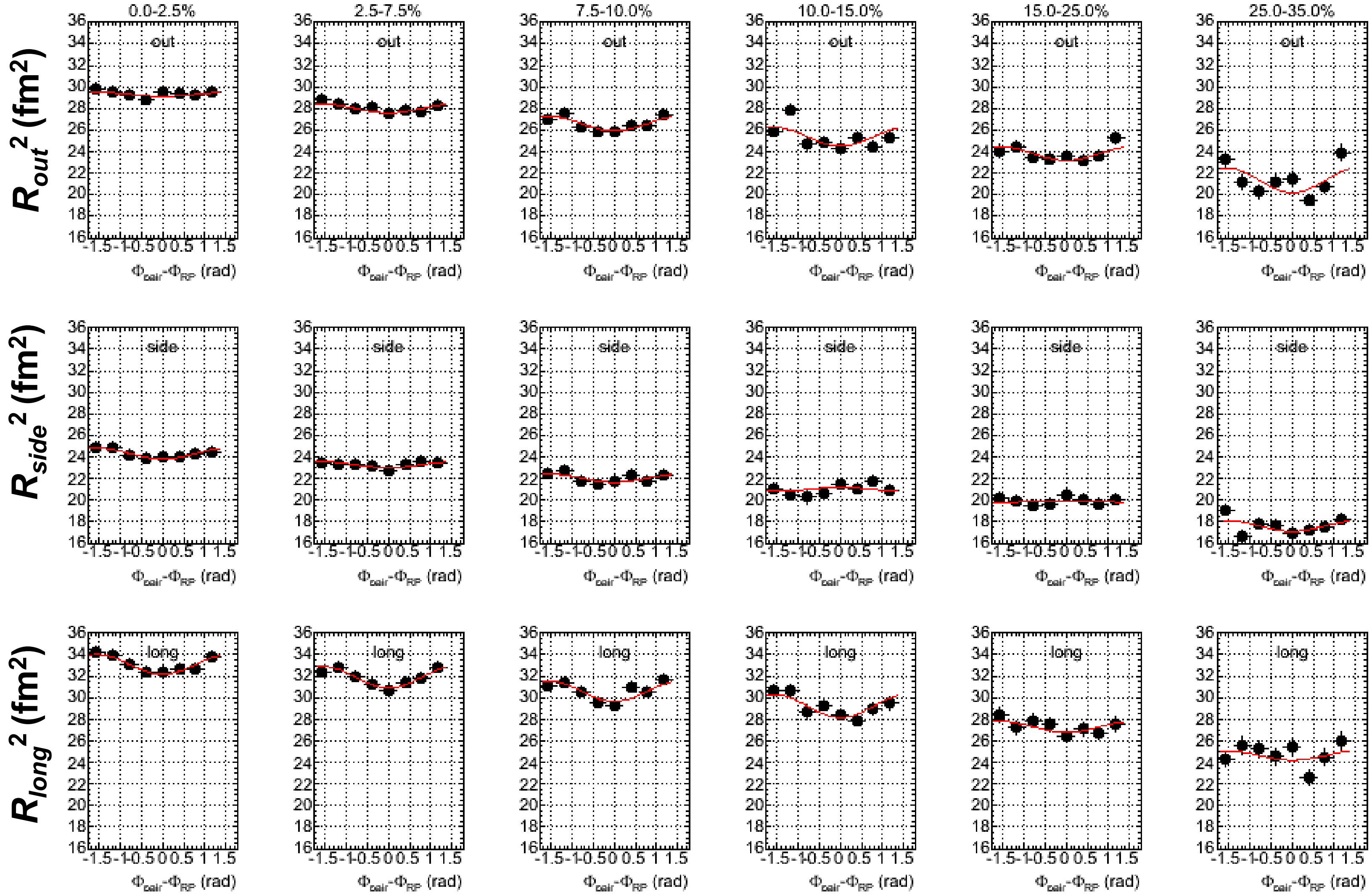
Gaussian source parameterization with R_x = 4 (fm), R_y = 5 (fm), R_z = 7 (fm)



azimuthal angle dependence of HBT radii

Pb+Au at 158 AGeV **D. Antonczyk**

central **semi-central**



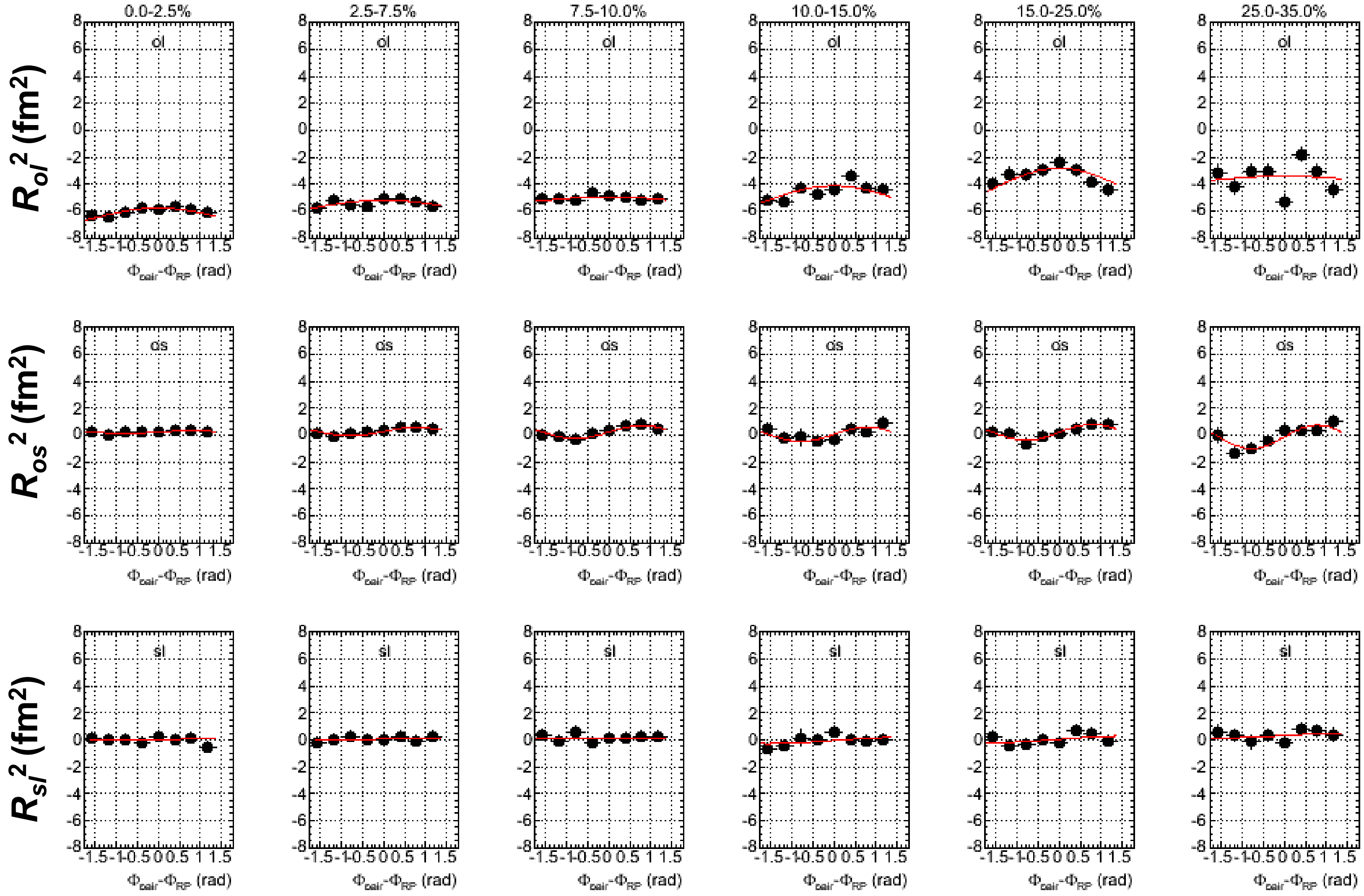
azimuthal angle dependence of HBT radii

Pb+Au at 158 AGeV

D. Antonczyk

central

semi-central

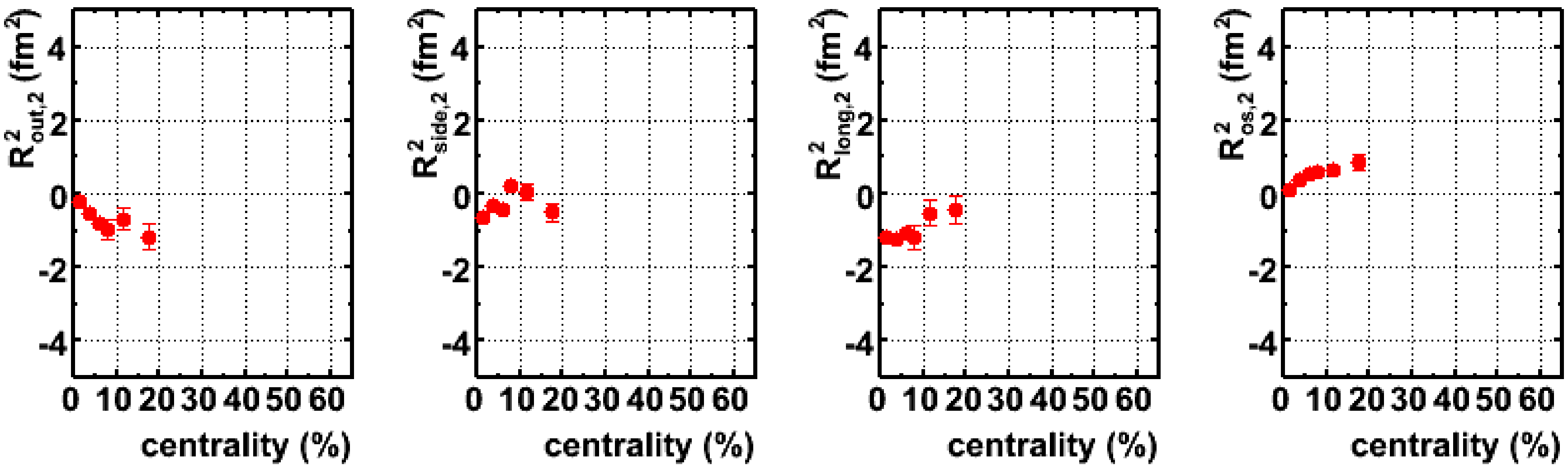


pion source size anisotropy

Pb+Au at 158 AGeV
preliminary

D. Antonczyk

parametrize the oscillation with $R_i^2 = R^2_{i,0} + 2\, R^2_{i,2} \cos[2(\Phi_{\pi\pi} - \Phi_{RP})]$ →



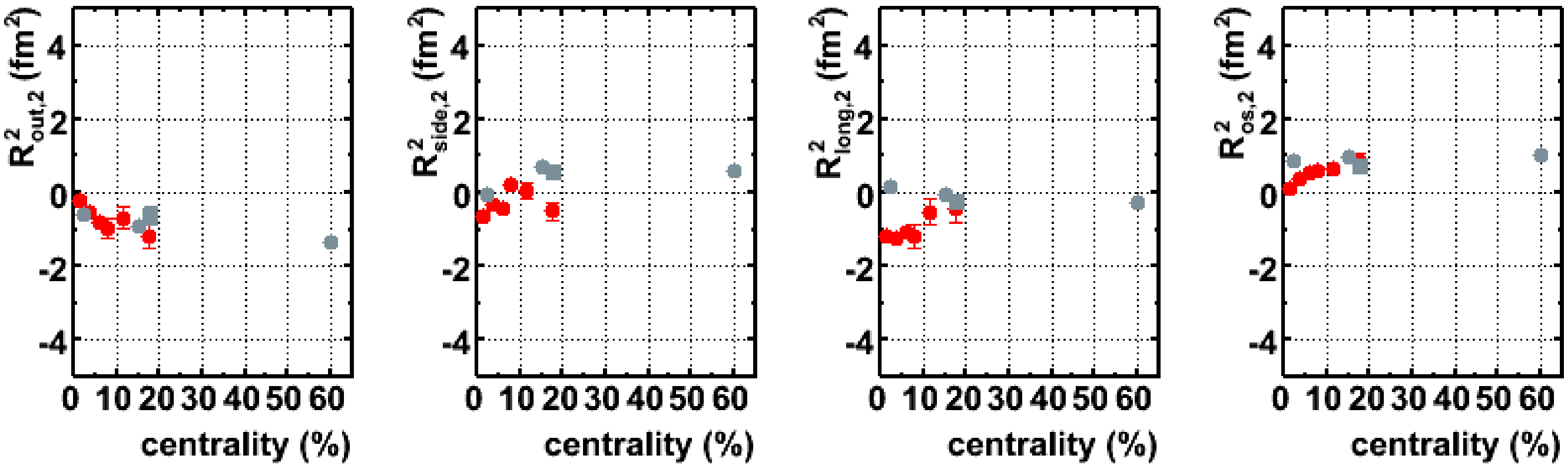
suggests an out-of-plane elongation

no effect -- inconsistent with R_{out}

significant -- against expectation and symmetry

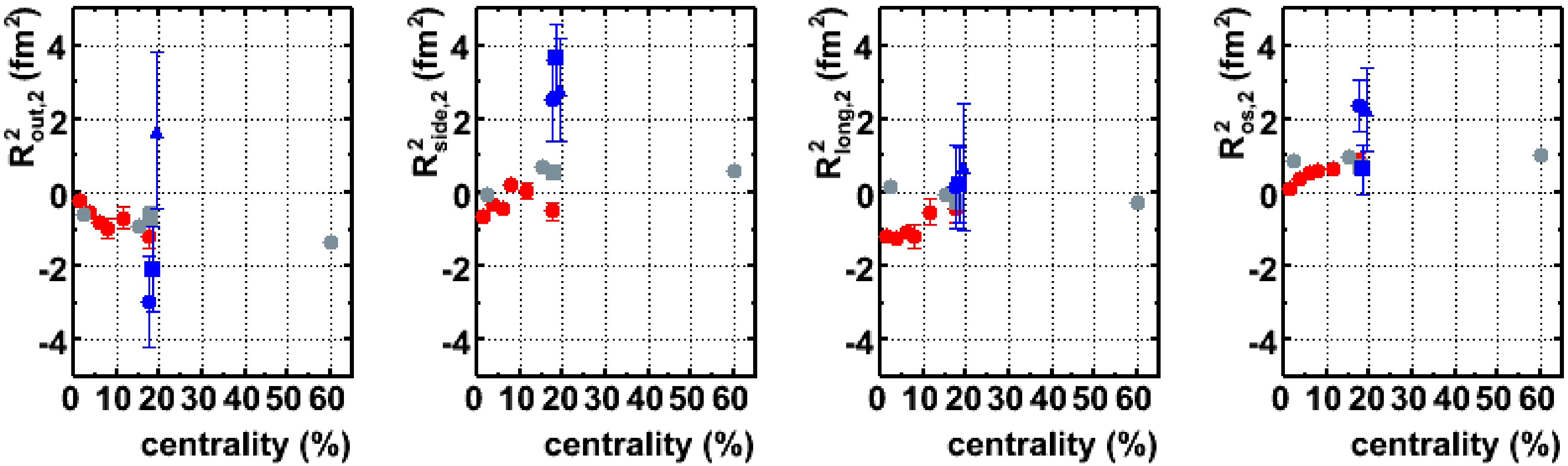
consistent with R_{out}

...compared to RHIC



● CERES	158 AGeV	<pt> = 0.47 GeV/c	D. Antonczyk, Ph.D.
■ STAR	sqrt(s) = 130 GeV	0.125<pt<0.45 GeV/c	
● STAR	sqrt(s) = 200 GeV	0.15<pt<0.6 GeV/c	PRL 93 (2004) 012301

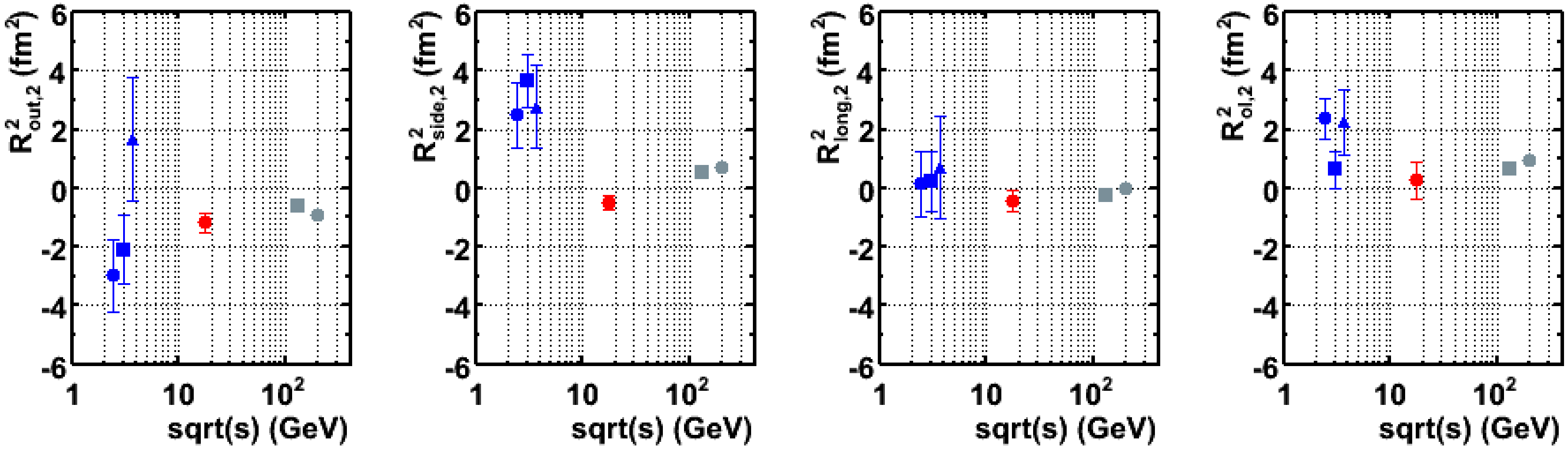
... and AGS



E895	*● 2, ■ 4, ▲ 6 AGeV*	*<pt> = 0.11 GeV/c*	*Phys. Lett. B 496 (2000) 1*
● CERES	*158 AGeV*	*<pt> = 0.47 GeV/c*	*D. Antonczyk, Ph.D.*
■ STAR	*sqrt(s) = 130 GeV*	*0.125<pt<0.45 GeV/c*	
● STAR	*sqrt(s) = 200 GeV*	*0.15<pt<0.6 GeV/c*	*PRL 93 (2004) 012301*

source anisotropy vs sqrt(s)

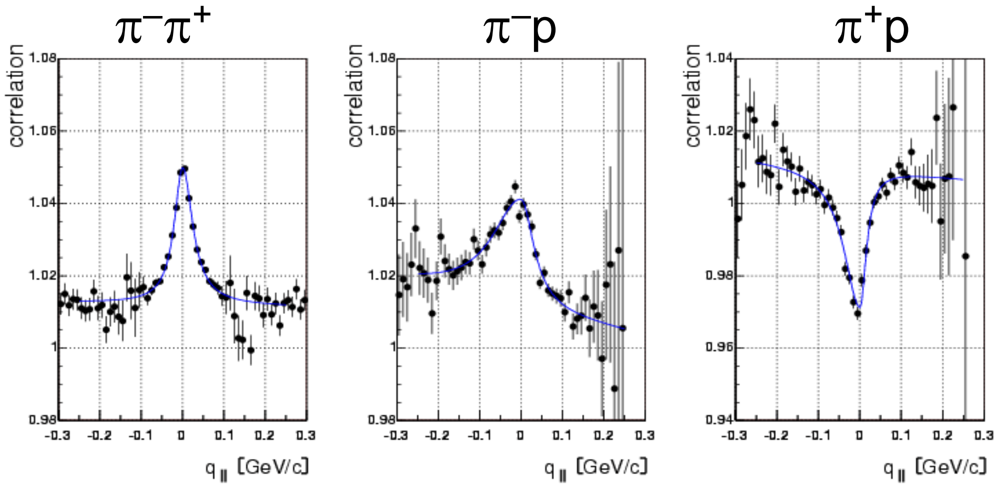
Pb+Au, Au+Au
centrality 15-20%



- ***non-monotonic behavior of R_{side}***
- ***R_{side} inconsistent with R_{out} → different freeze-out times in-plane and out-of-plane?***

pion-proton correlations

central Pb+Au at 158 AGeV
Dariusz Antonczyk

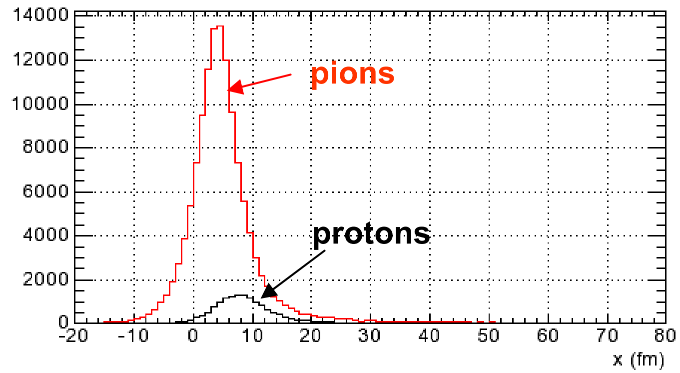


asymmetry of correlation function is related to the asymmetry of the relative source distribution (Lednicky, Phys.Lett.B373(96)30)

proton source at larger transverse radius than pion source (or earlier emission)

most probable origin: transverse flow

pion and proton sources in UrQMD



blast wave model

Retière, Lisa, PRC 70(2004)044907

analytic hydro-inspired 8-d emission function

$$S(x,K) = m_T \cosh(\eta - Y)\, \Omega(r,\phi_S)\, e^{\frac{-(\tau-\tau_0)^2}{2\Delta\tau^2}} \frac{1}{e^{K\cdot u/T} \pm 1}$$

with the space profile

$$\Omega(r,\phi_S) = \Omega(\tilde{r}) = \frac{1}{1+e^{(\tilde{r}-1)/a}}$$

and the normalized elliptic radius

$$\tilde{r}(r,\phi_S) = \sqrt{\frac{(r\cos(\phi_S))^2}{R_x^2} + \frac{(r\sin(\phi_S))^2}{R_y^2}}$$

and the flow four-velocity

$$u = u_\mu(x, \rho_0, \rho_2)$$

blast wave model

analytic hydro-inspired 8-d emission function

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and the flow four-velocity

$$u = u_\mu(x, \rho_0, \rho_2)$$

function of four space-time coordinates

blast wave model

analytic hydro-inspired 8-d emission function

$$S(x,K) = m_T \cosh(\eta - Y)\,\Omega(r,\phi_S)\, e^{\frac{-(\tau-\tau_0)^2}{2\Delta\tau^2}} \frac{1}{e^{K\cdot u/T} \pm 1}$$

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and the normalized elliptic radius

$$\tilde{r}(r,\phi_S) = \sqrt{\frac{(r\cos(\phi_S))^2}{R_x^2} + \frac{(r\sin(\phi_S))^2}{R_y^2}}$$

and the flow four-velocity

$$u = u_\mu(x,\rho_0,\rho_2)$$

function of four momentum components

blast wave model

analytic hydro-inspired 8-d emission function

$$S(x,K) = m_T \cosh(\eta - Y)\,\Omega(r,\phi_S)\, e^{\frac{-(\tau-\tau_0)^2}{2\Delta\tau^2}} \frac{1}{e^{K\cdot u/T} \pm 1}$$

with the space profile

$$\Omega(r,\phi_S) = \Omega(\tilde{r}) = \frac{1}{1+e^{(\tilde{r}-1)/a}}$$

and the normalized elliptic radius

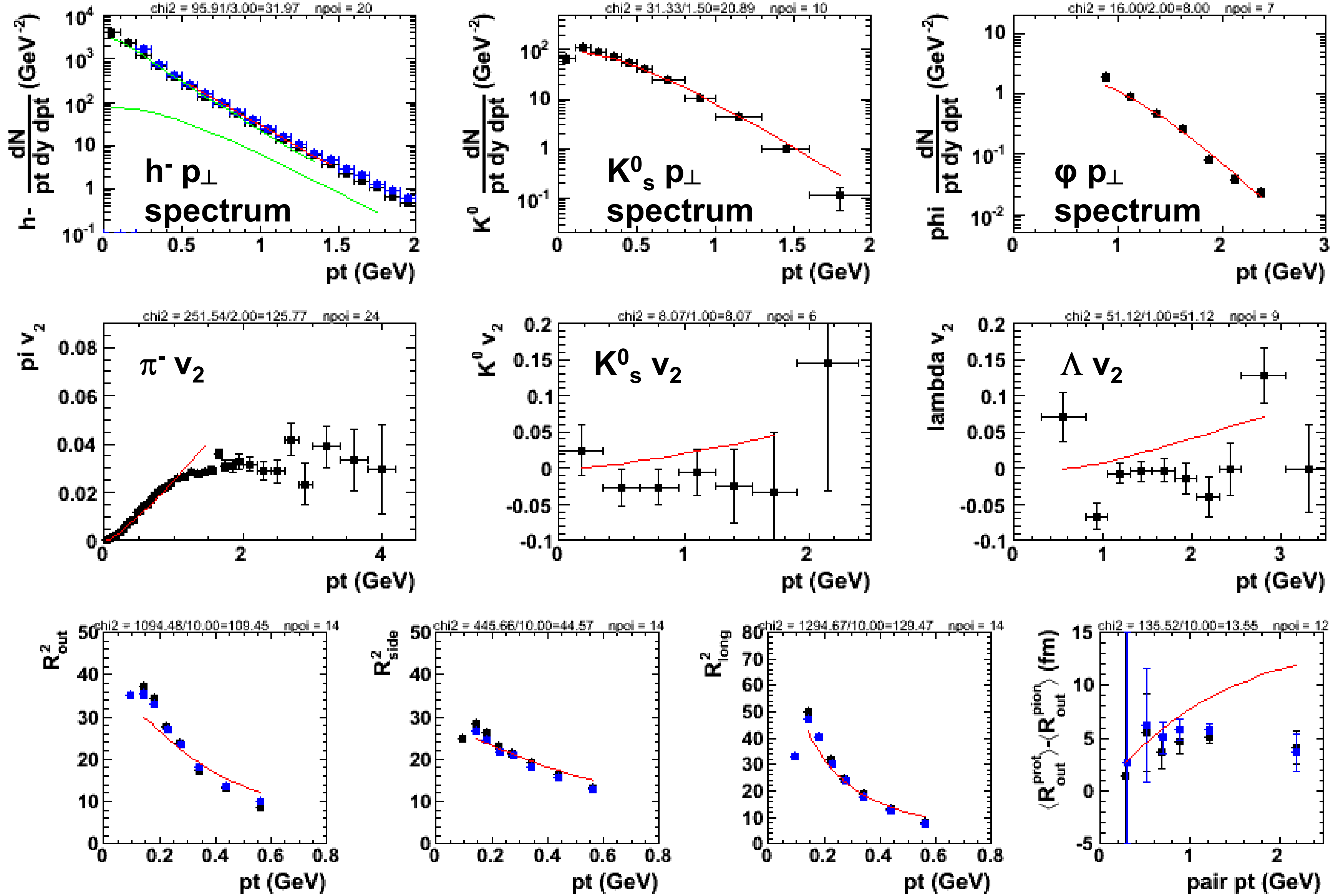
$$\tilde{r}(r,\phi_S) = \sqrt{\frac{(r\cos(\phi_S))^2}{R_x^2} + \frac{(r\sin(\phi_S))^2}{R_y^2}}$$

and the flow four-velocity

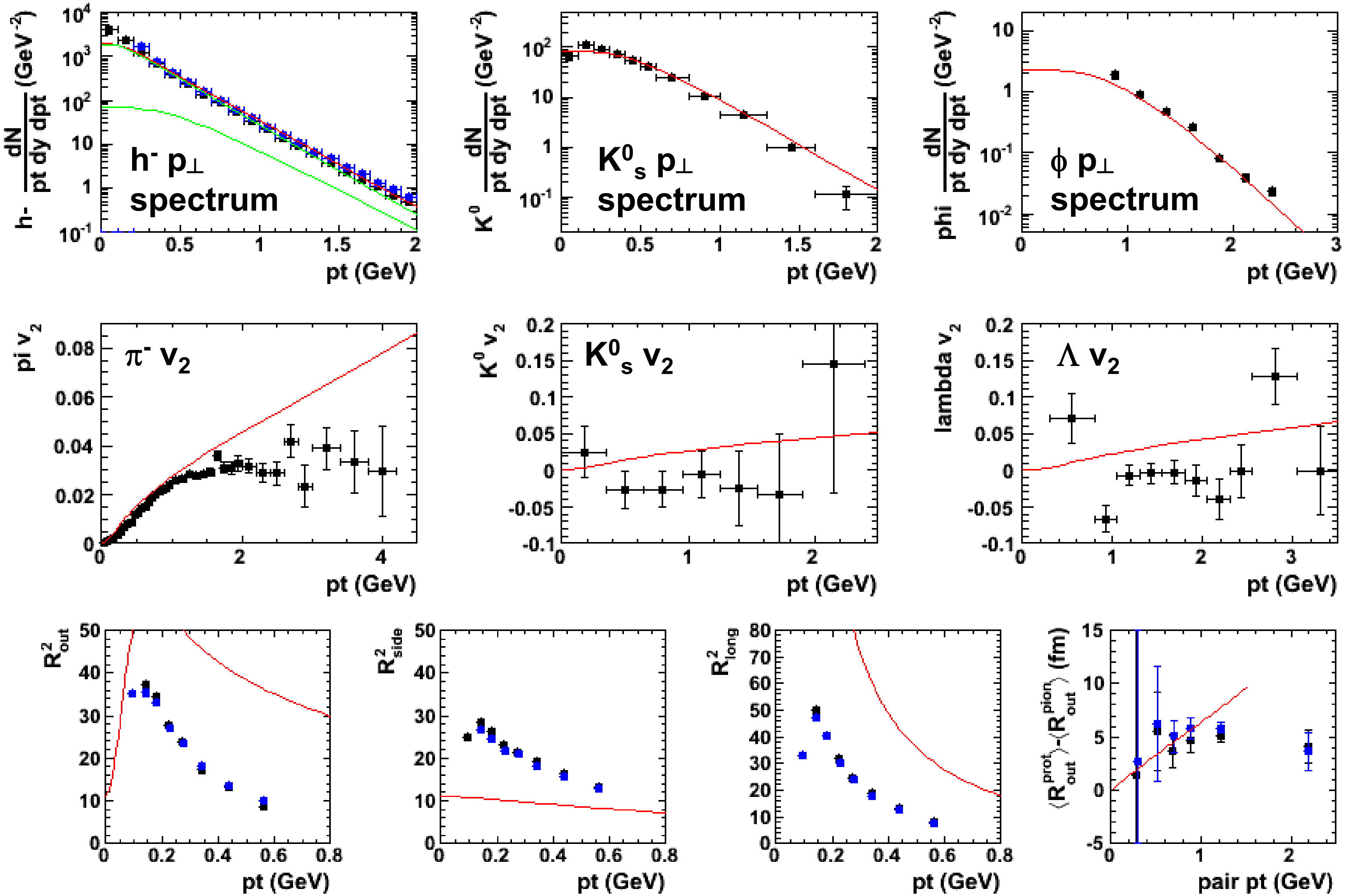
$$u = u_\mu(x, \rho_0, \rho_2)$$

with eight parameters

CERES (points) and blast T=100 MeV (lines)



CERES (points) and hydro T=120 MeV (lines)



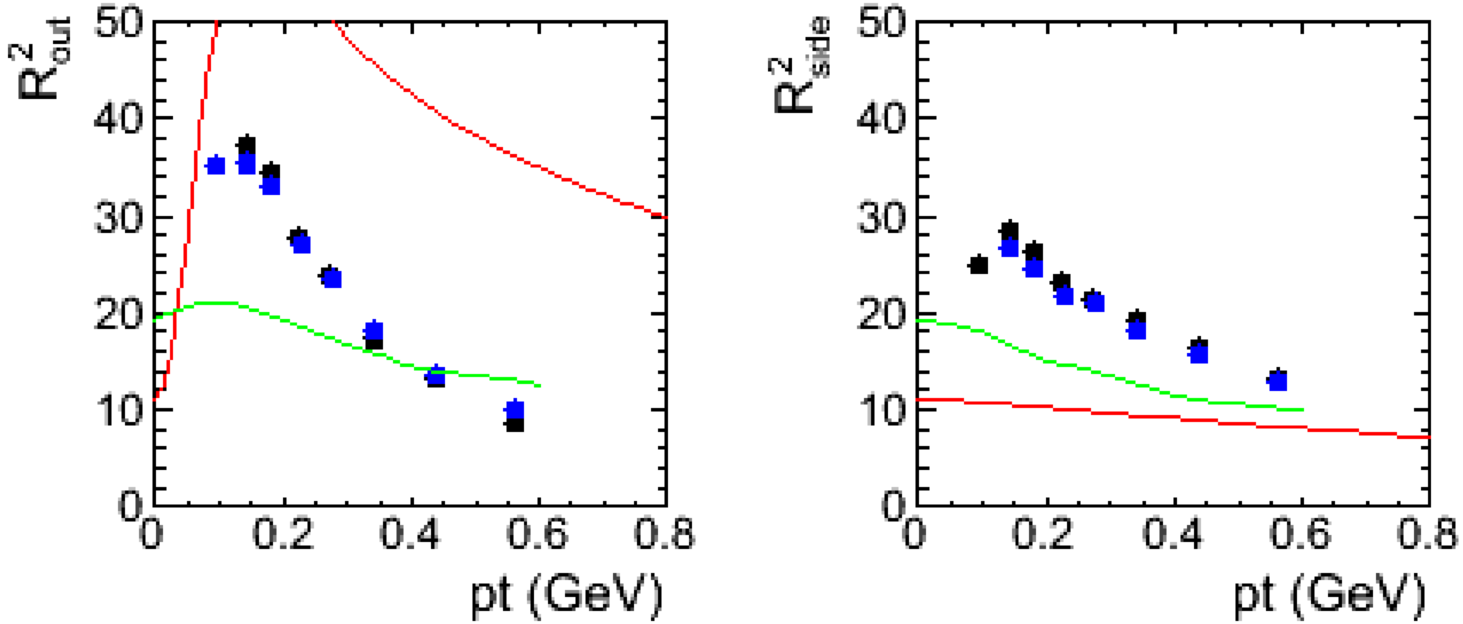
puzzle

hydro

~~RHIC~~ HBT puzzle

try another flavour of hydro

black and blue points: CERES data
red line: present day hydro (Pasi Huovinen)
green line: old days hydro (Bernd Schlei)



Ornik, Plümer, Schlei, Strottman, Weiner PRC 54(1996)1381, Pb+Pb at 160A GeV; rapidity and centrality not matched to CERES data so detailed comparison not possible; but, in any case...

Rout/Rside totally different from the present hydro

part of the puzzle?

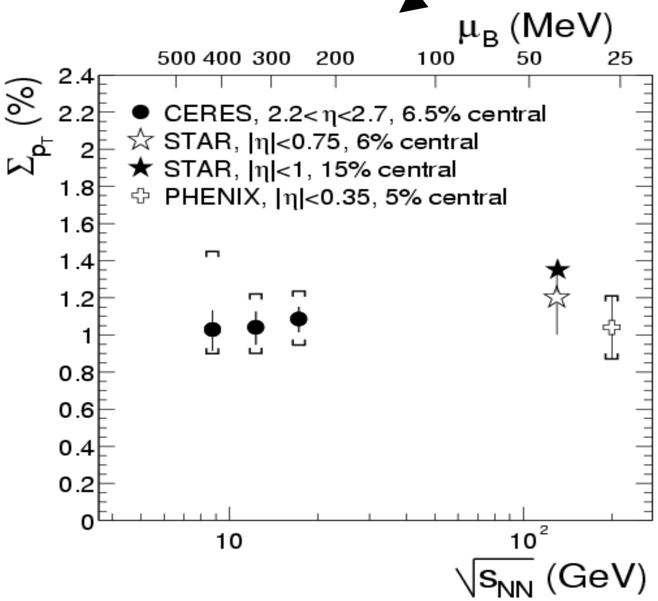
hydro $\neq$ hydro

pt fluctuations

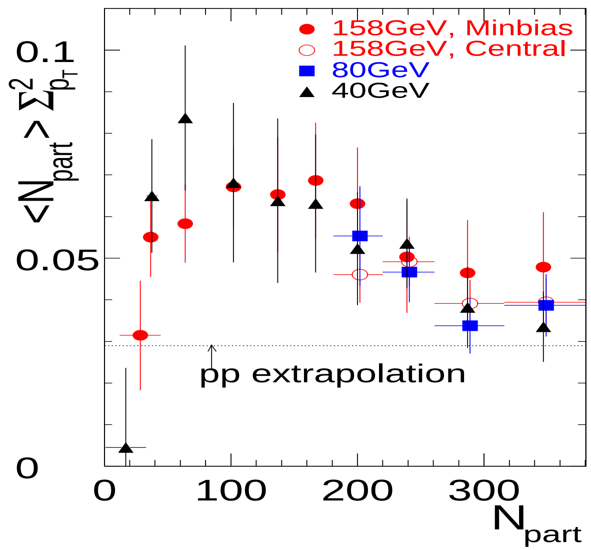
motivation:
enhanced fluctuations at critical point

difficulty:
distinguish from trivial fluctuations (statistical, centrality, HBT, elliptic flow...)

observation:
non-statistical fluctuations exist, indeed
flat vs beam energy
non-monotonic vs centrality



(CERES collaboration,
Nucl. Phys. A727(2003)97,
***J.Phys.G30(2004)S1376*)**



pt fluctuations strategy: analyze pt-pt correlations as a function of $\Delta\eta$ and $\Delta\varphi$

measures of fluctuations

$\sigma_{pt\ dyn}^2$	difference between the variances of pt and mean pt
Σ_{pt}^2	same divided by mean pt
$\langle \Delta pt_i, \Delta pt_j \rangle$	pt covariance
Φ_{pt}	difference between the standard deviations of pt and mean pt

relations

$$\sigma_{pt\ dyn}^2 = \sigma_{\langle pt \rangle}^2 - \sigma_{pt}^2 / \langle M \rangle$$

$$\Sigma_{pt} = \sigma_{pt\ dyn} / \langle pt \rangle$$

$$\langle \Delta pt_i, \Delta pt_j \rangle \cong \sigma_{pt\ dyn}^2$$

$$\Phi_{pt} \cong \langle M \rangle \sigma_{pt\ dyn}^2 / 2\sigma_{pt}$$

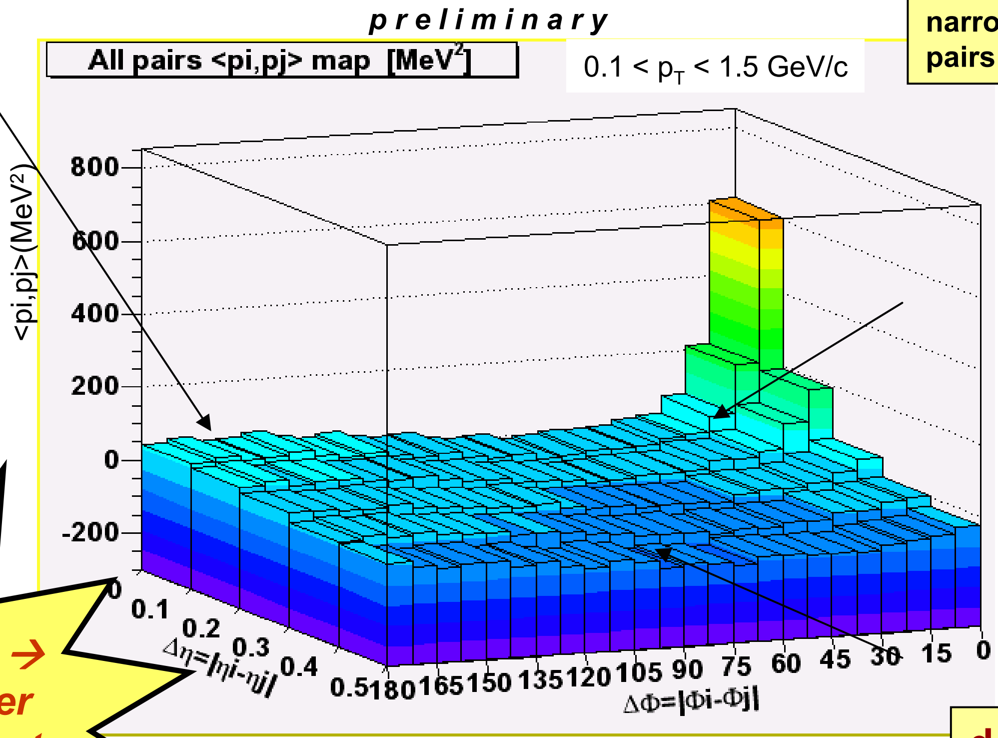
pt fluctuations

Pb+Au at 158 AGeV

Harry Appelshaeuser
Georgios Tsiledakis

away-side correlations

elliptic flow, jets?



short range correlations

confined to Q_{INV}<70 MeV
narrower and weaker for unlike pairs → HBT and Coulomb?

decline with Δη

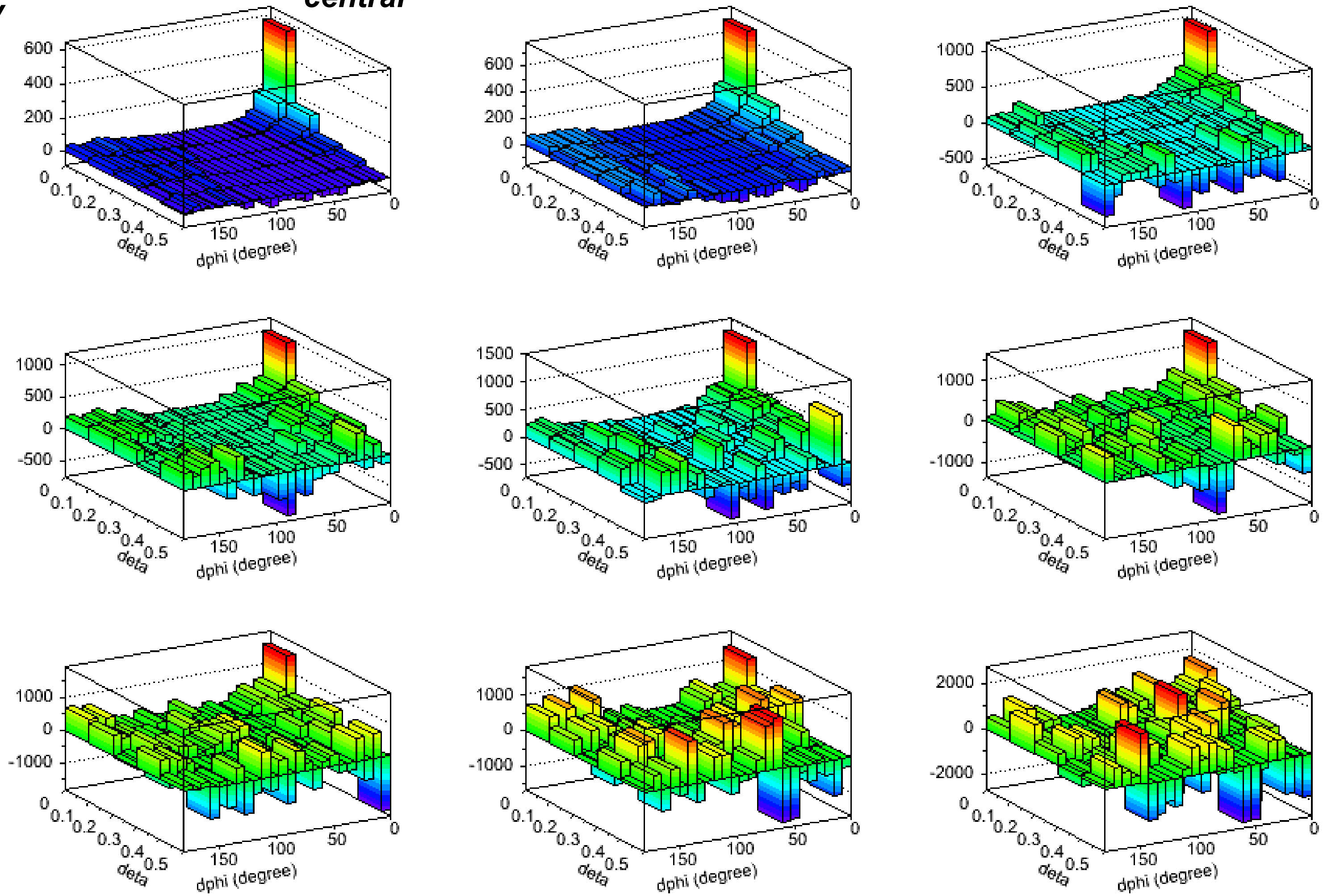
reproduced with event mixing
trivial effect of pt(η) dependence?

rich structure → averaging over Δϕ and Δη is not good

pt covariance at 158 GeV: centrality dependence

Pb+Au at 158 AGeV preliminary

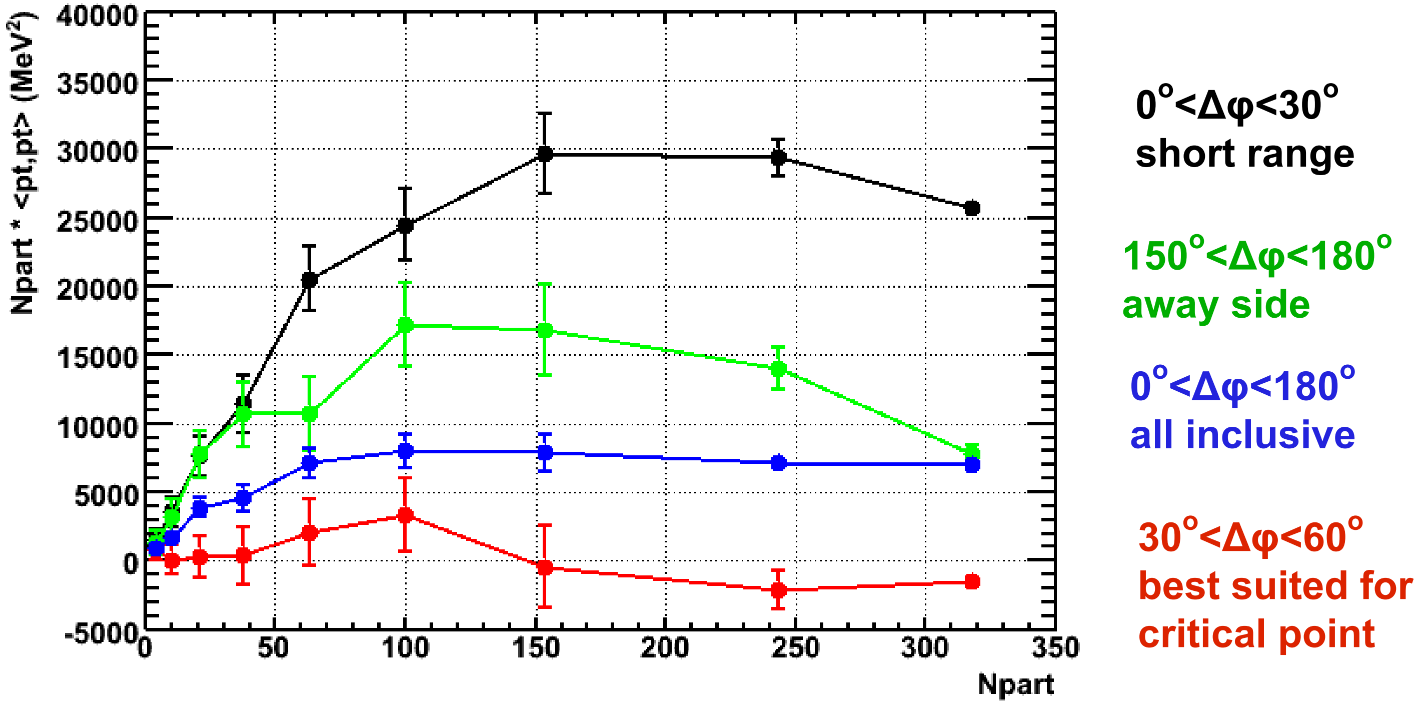
central



peripheral

pt covariance at 158 GeV: centrality dependence

Pb+Au at 158 AGeV
preliminary



the observed centrality dependence comes from the short-range and the away-side correlations

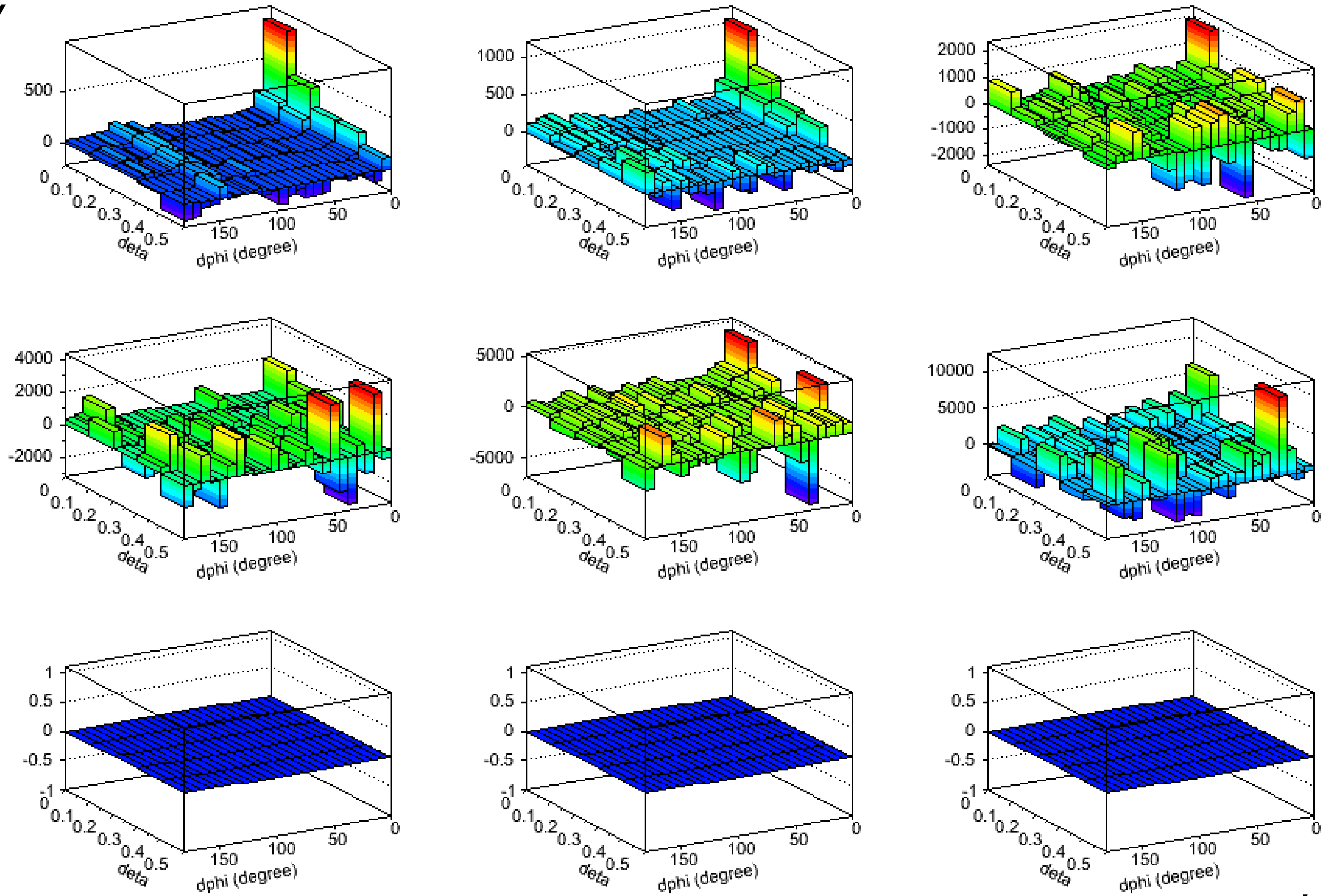
30°<Δφ<60° region, which is free of these effects and of elliptic flow, shows no signal

pt covariance at 80 GeV:

centrality dependence

Pb+Au at 80 AGeV
preliminary

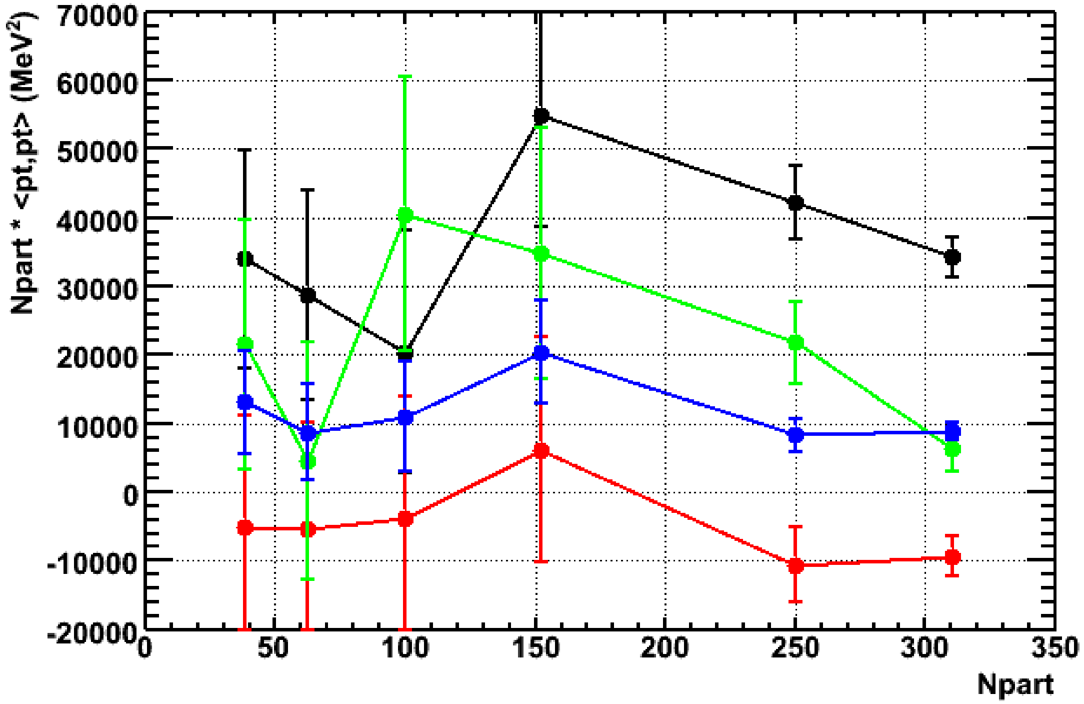
central



peripheral

pt covariance at 80 GeV: centrality dependence

Pb+Au at 80 AGeV
preliminary



$0^o < \Delta\varphi < 30^o$
short range

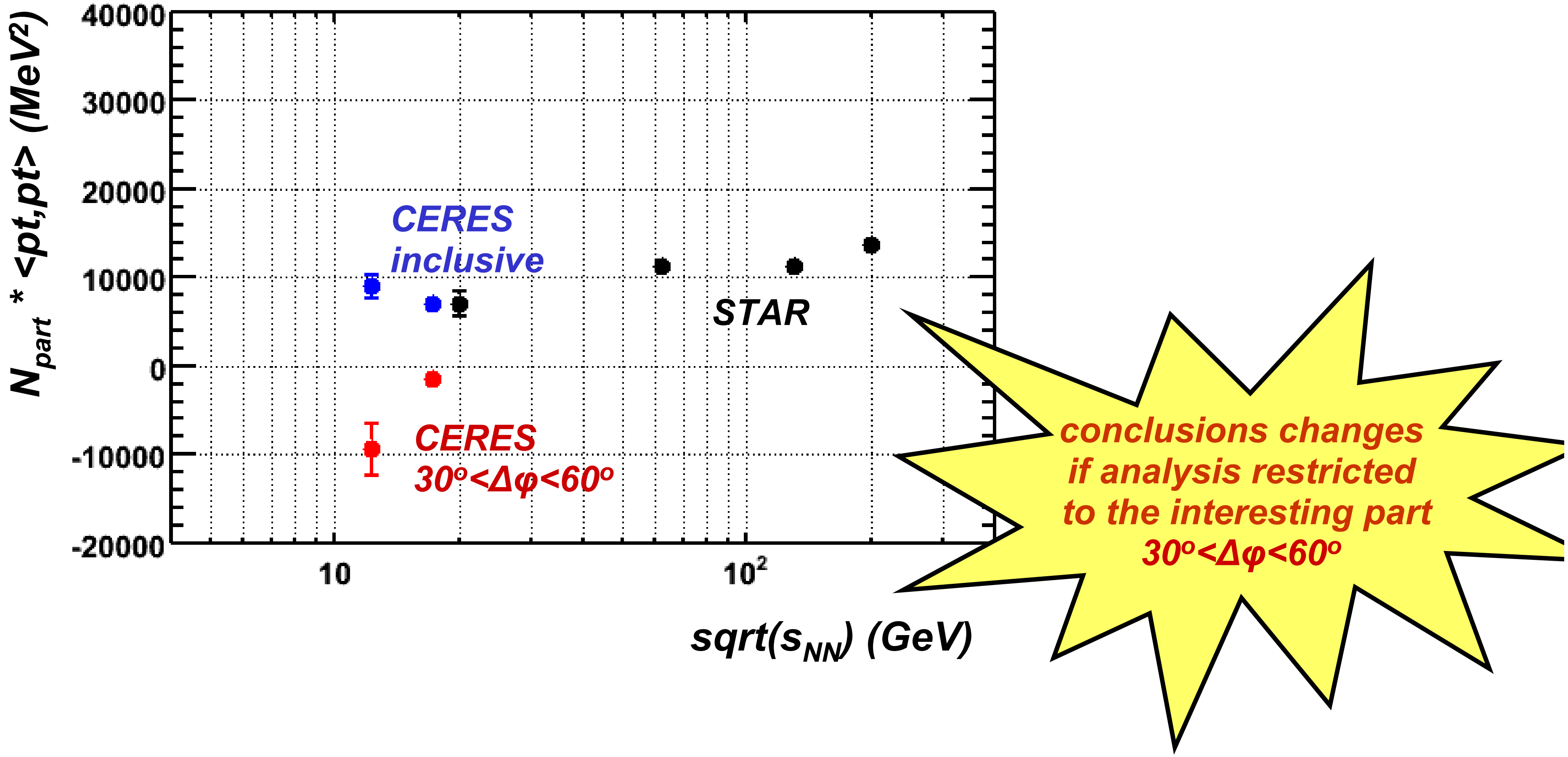
$150^o < \Delta\varphi < 180^o$
away side

$0^o < \Delta\varphi < 180^o$
all inclusive

$30^o < \Delta\varphi < 60^o$
best suited for critical point

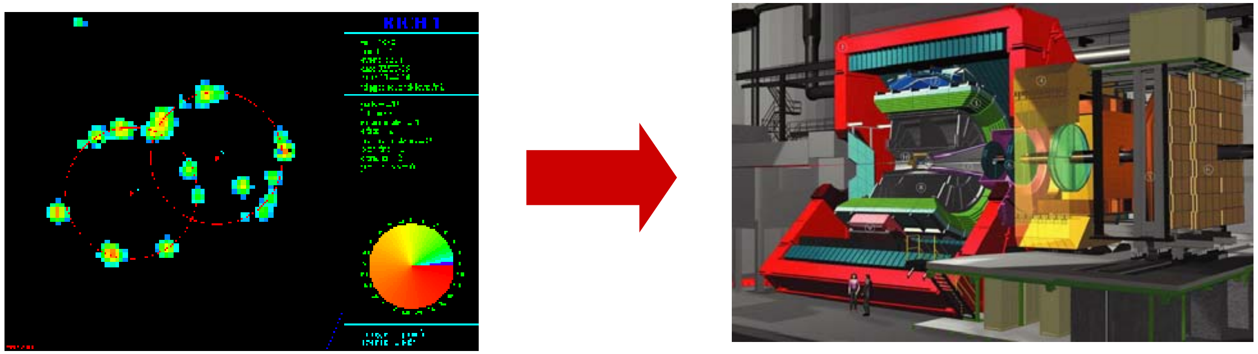
pt covariance: beam energy dependence

CERES central Pb+Au 158 AGeV preliminary
STAR central Au+Au 20-200 GeV PRC 72 (2005) 044902



summary... and outlook

- running at SPS 1990-2000
- 58 members
- 57 publications (SPIRES)
- 1318 citations
- practically all members now working in ALICE

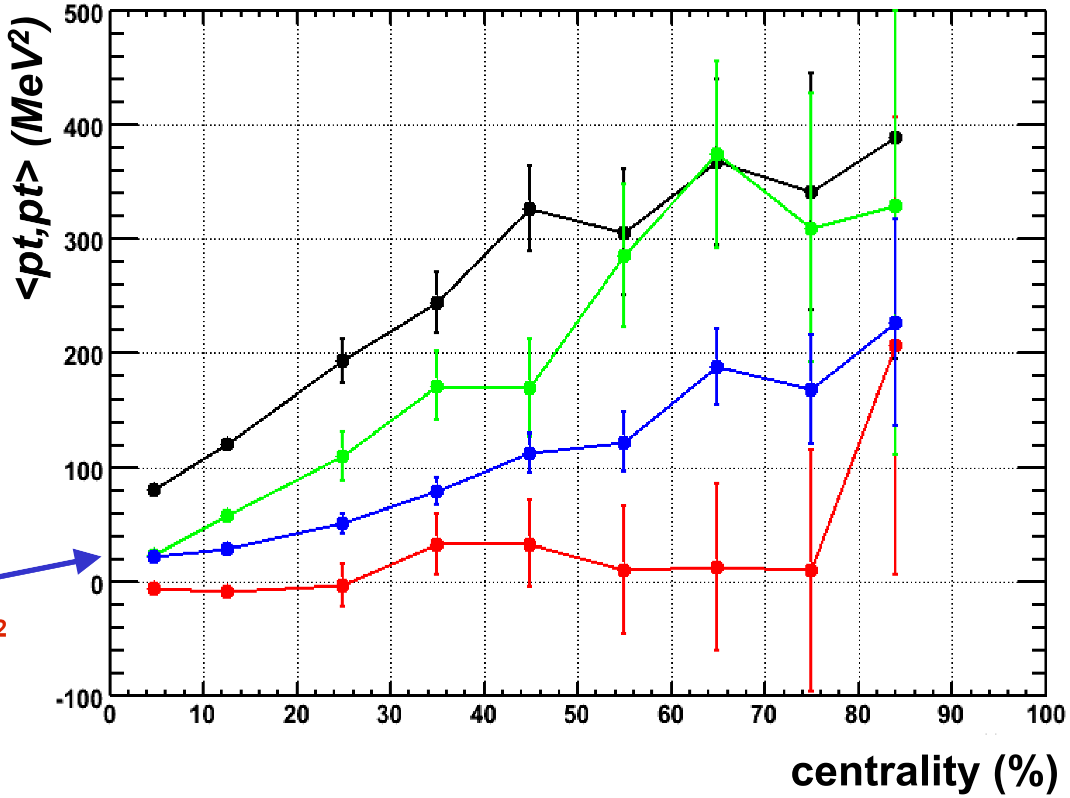


backup slides

pt covariance at 158 GeV: centrality dependence

Pb+Au at 158 AGeV
preliminary

published
inclusive
analysis
value 22 MeV^2



$0^o<\Delta\varphi<30^o$
short range

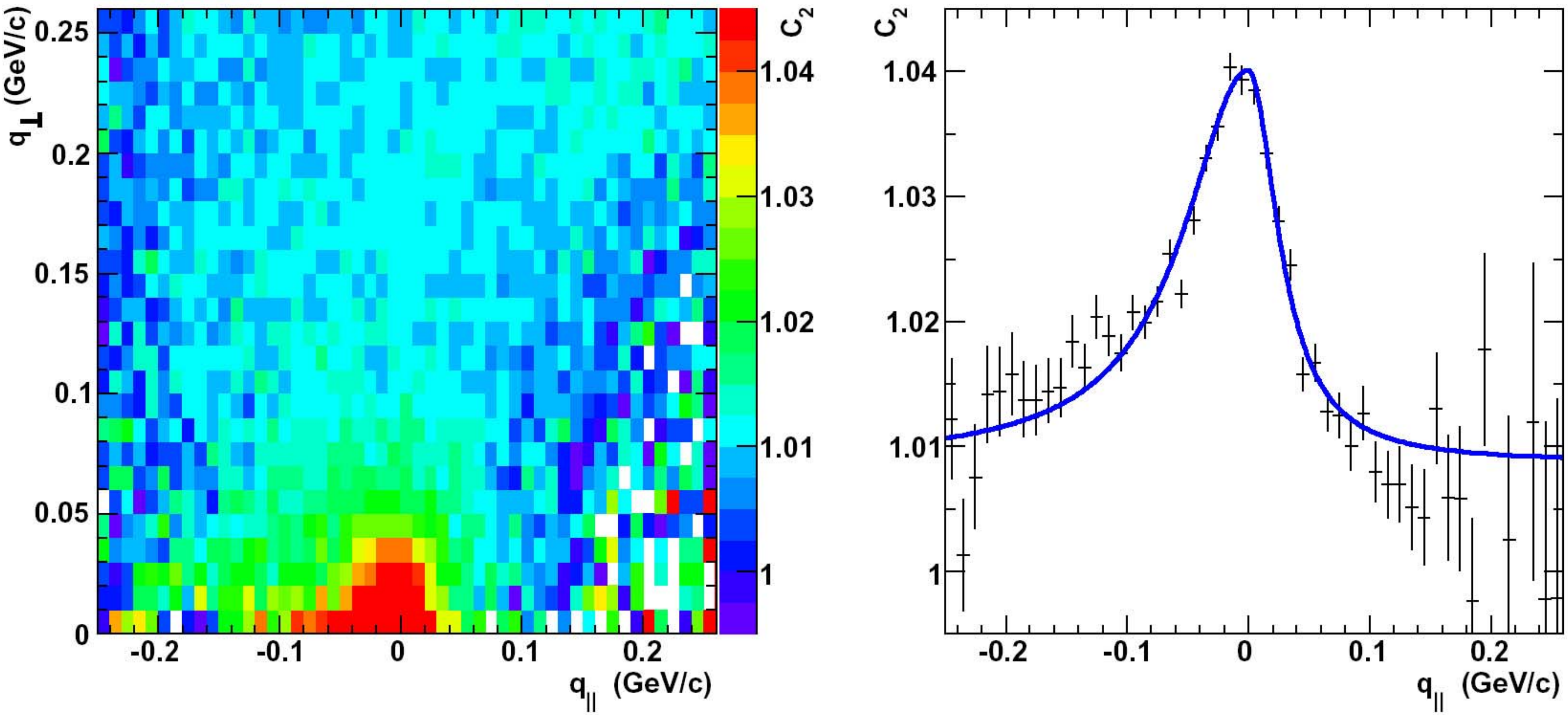
$150^o<\Delta\varphi<180^o$
away side

$0^o<\Delta\varphi<180^o$
all inclusive

$30^o<\Delta\varphi<60^o$
best suited for
critical point

Extracting the asymmetry

π^- - proton correlation



take a slice and project on $q_{||}$
fit each half separately with......... $$C(q_{||}) = 1 + \frac{A}{1 + q_{||}^{\,2} / B^2}$$
require same A
B is HWHM
asymmetry = B_{left}/B_{right}

Fitting R_{side} and Δx

$$R_{side}(p_\perp) = \frac{R_G}{\sqrt{1 + \frac{m_\perp \eta_f^2}{T}}}$$

$$m_\perp = \sqrt{m_\pi + \left(\frac{P_\perp}{2}\right)^2}$$

U. Heinz, many many papers

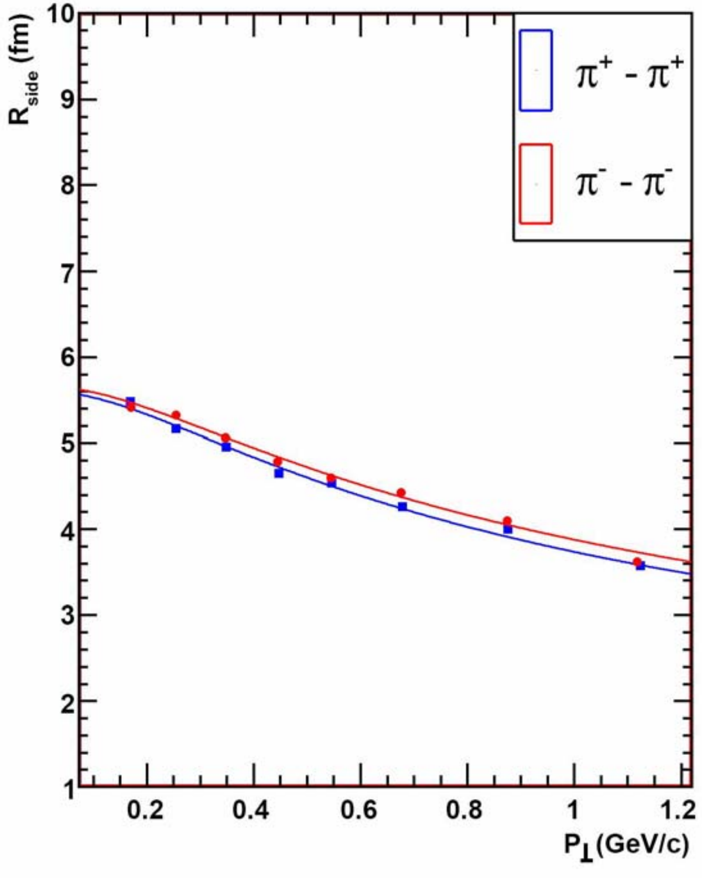
$$\langle \Delta x \rangle = \frac{R_G \beta_\perp \beta_0}{\beta_0^2 + \frac{T}{m_\perp}}$$

$$m_\perp = \sqrt{m_\perp^1 m_\perp^2}$$

$$\eta_f = \frac{1}{2} \log \frac{1+\beta_0}{1-\beta_0}$$

$$\beta_\perp = \frac{1}{\sqrt{1 + \left(\frac{m_\pi + m_p}{P_\perp}\right)^2}}$$

R. Lednicky, nucl-th/0305027, based on Akkelin, Sinyukov Z.Phys.C 72(1996)501



R_{side} dominates the fit
Δx agrees reasonably well
→ all flow?

Fitting R_{side} and Δx

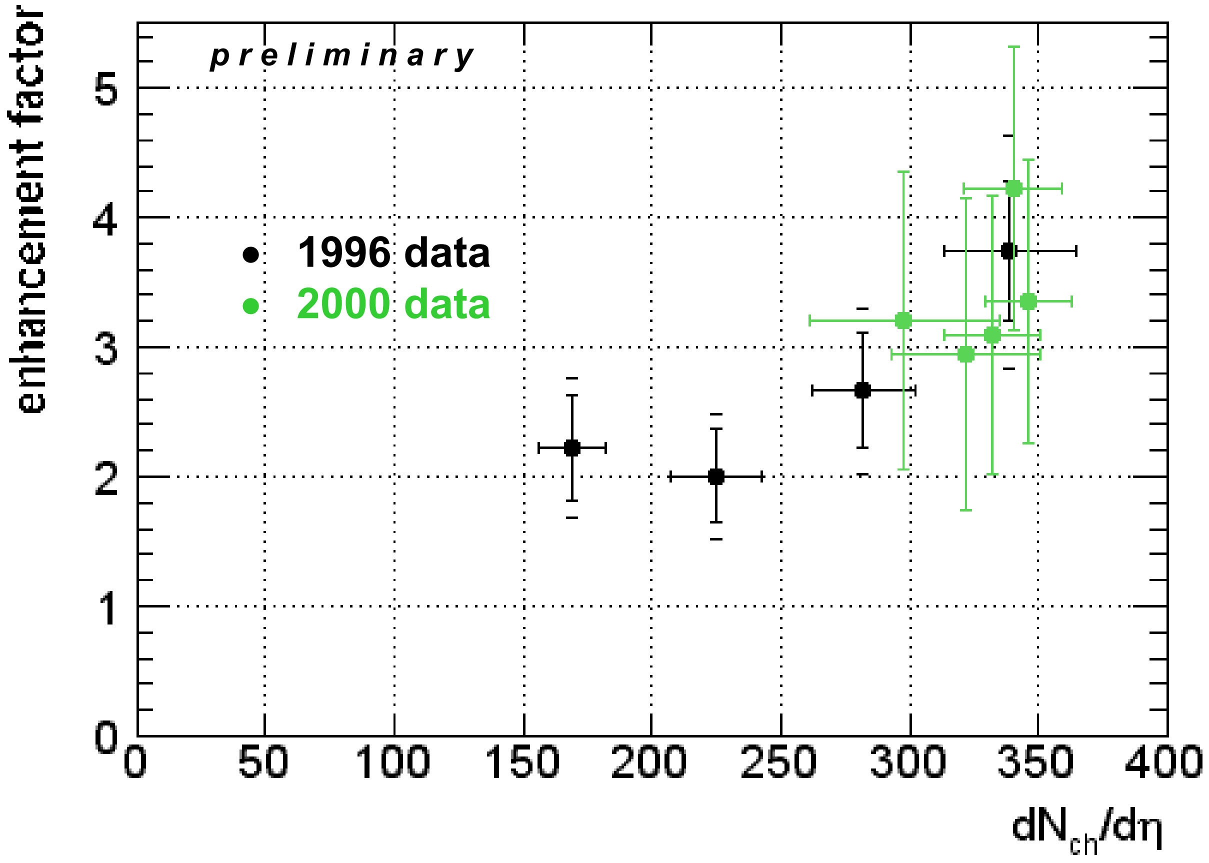
fixed T=120 MeV

	β_0	R_G (fm)
$\pi^+ p$	0.695 (7)	7.64 (7)
$\pi^- p$	0.655 (6)	7.41 (12)
$\pi^+ p$ and $\pi^- p$	0.663 (4)	7.42 (12)

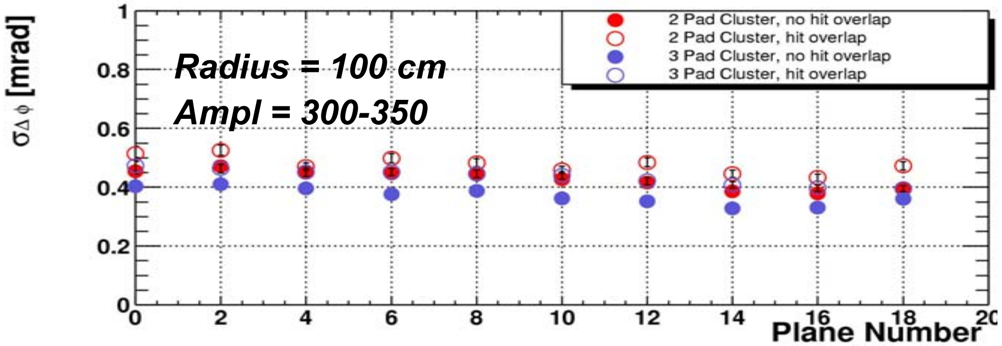
e^+e^- enhancement: centrality dependence

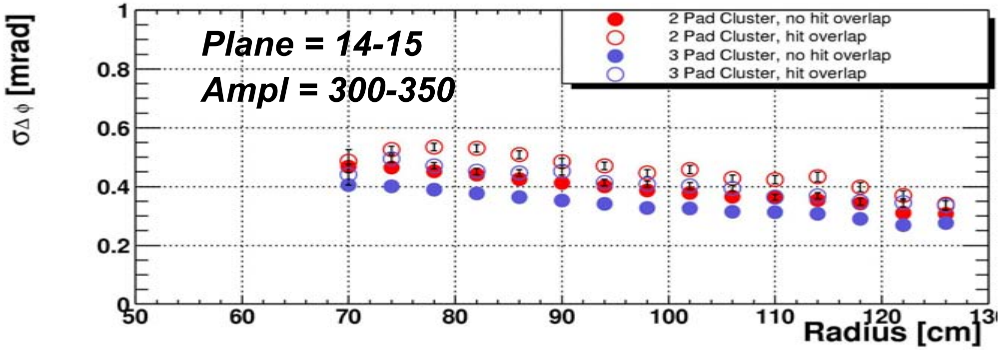
Pb+Au at 158 GeV per nucleon

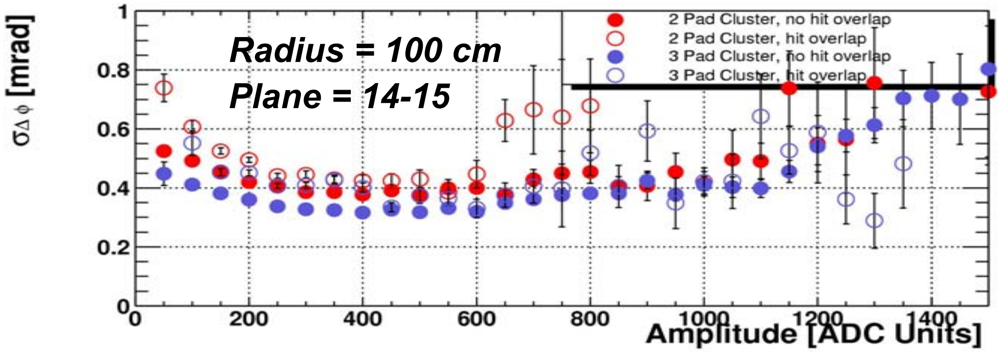
Sergey Yurevich



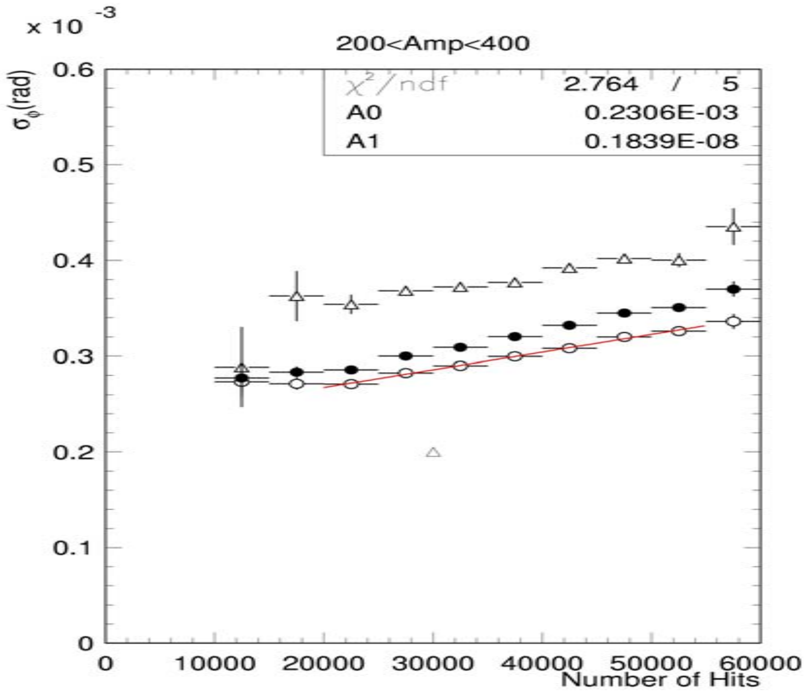
final position resolution



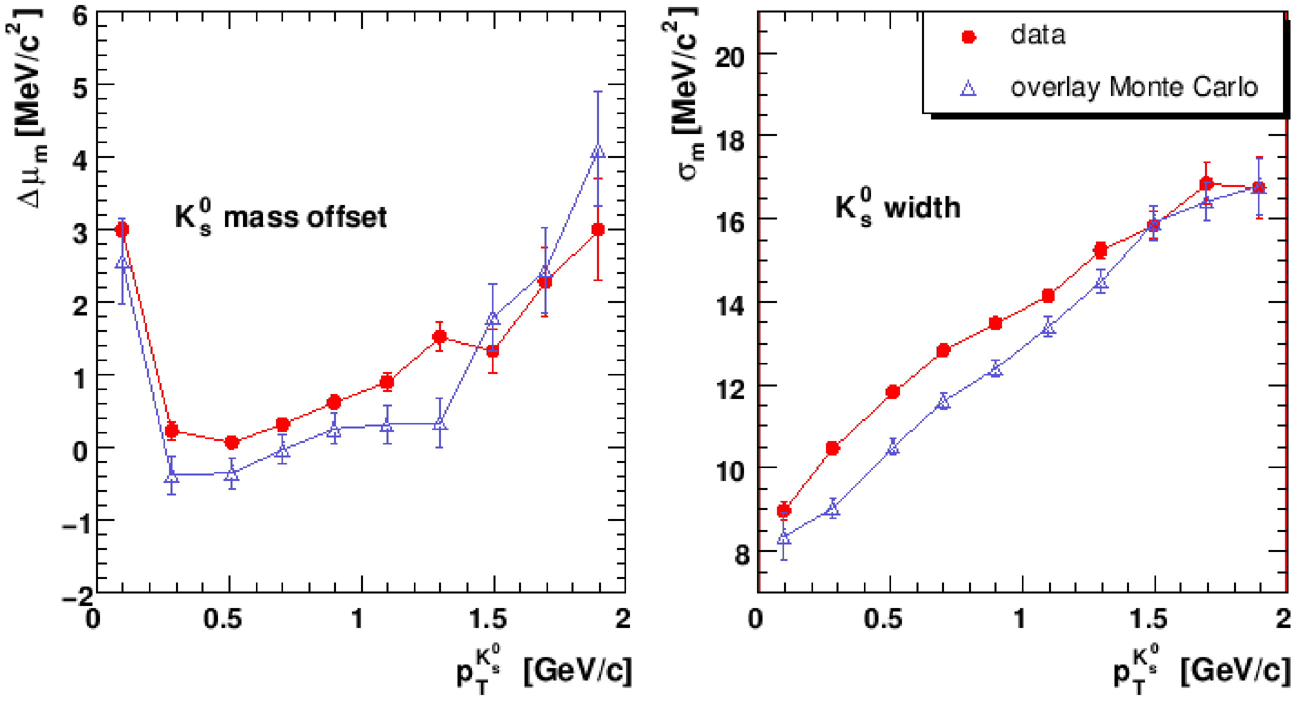




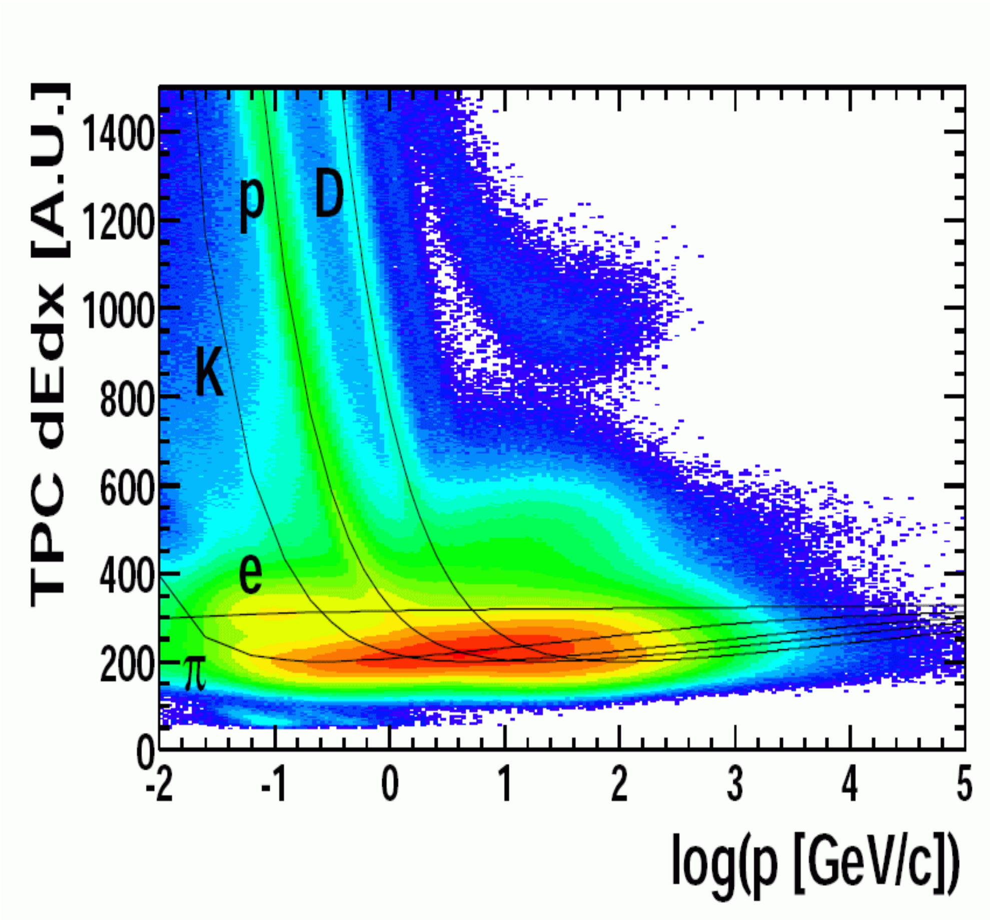
hit multiplicity: 24-26 k; typical central: 20-50 k
typical amplitude for electrons: 270-350

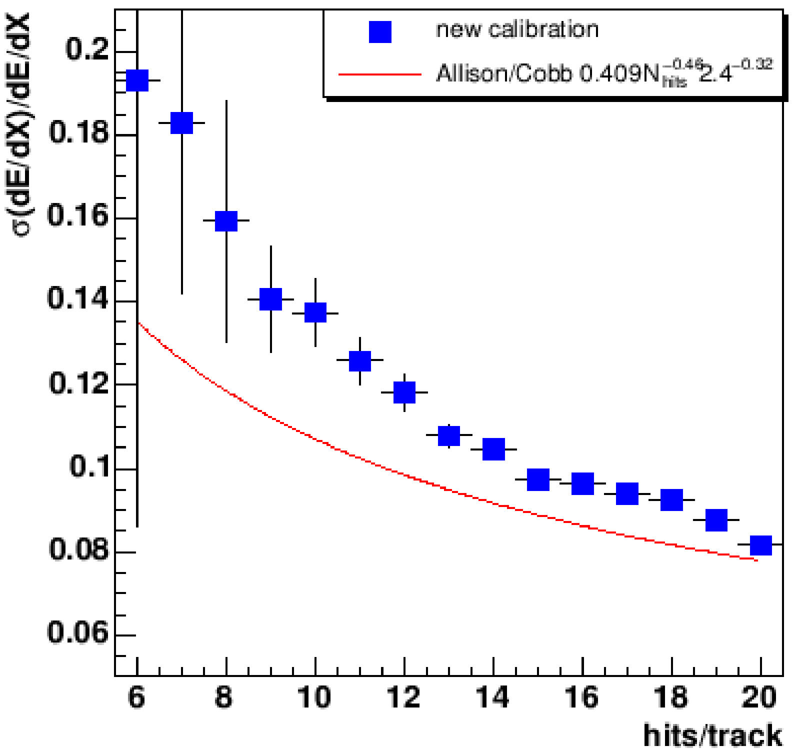


final mass resolution

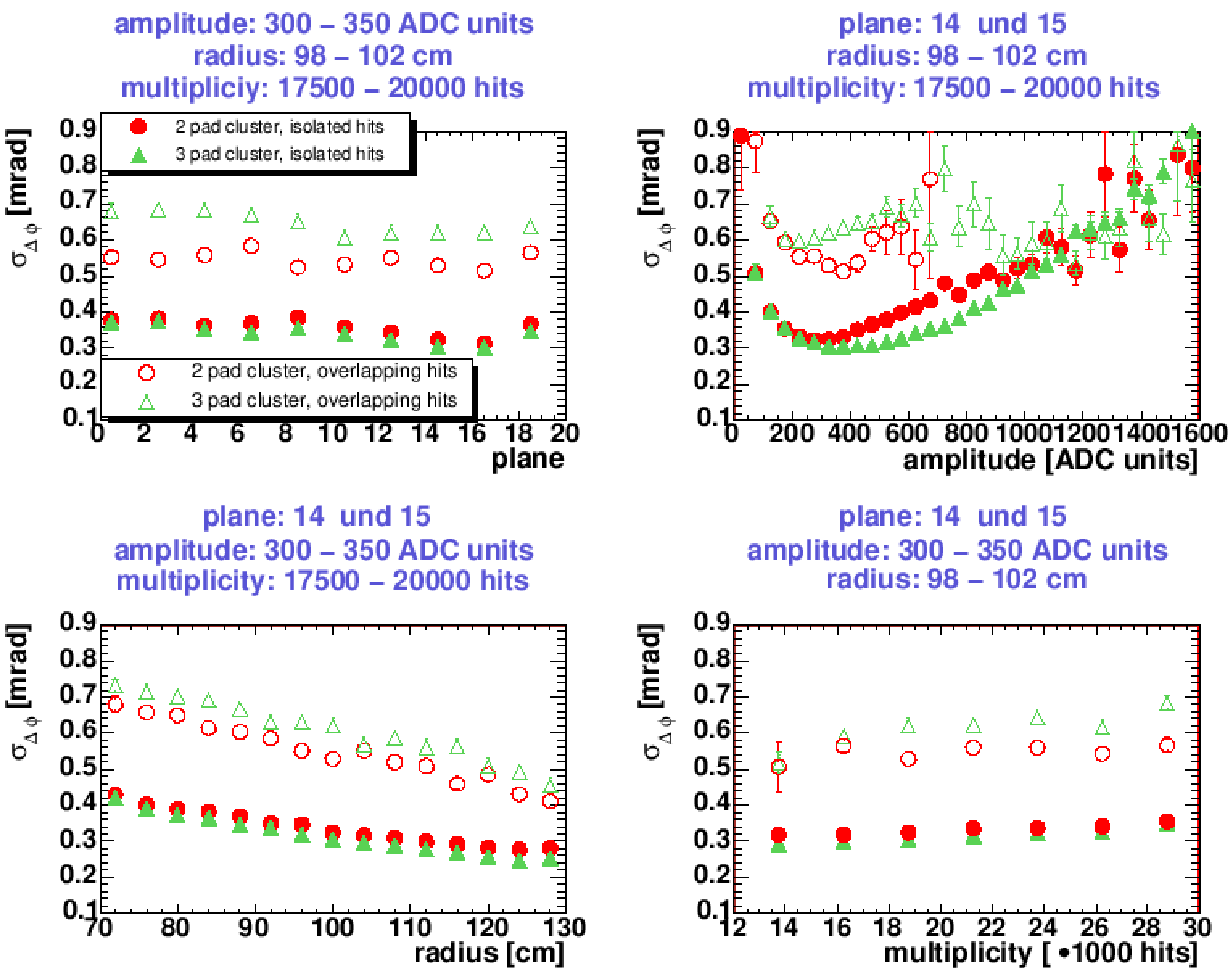


final dE/dx resolution



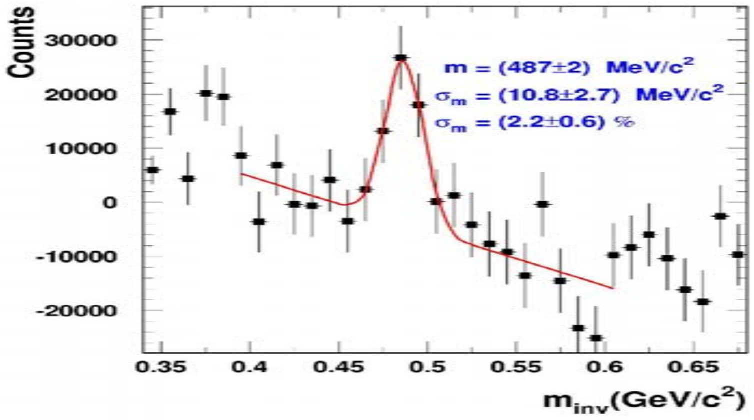


final position resolution

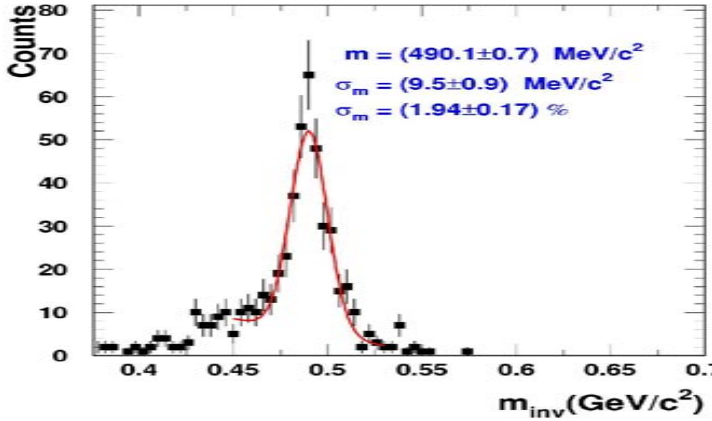


final momentum resolution

Pb+Au in 2000, 590 k events

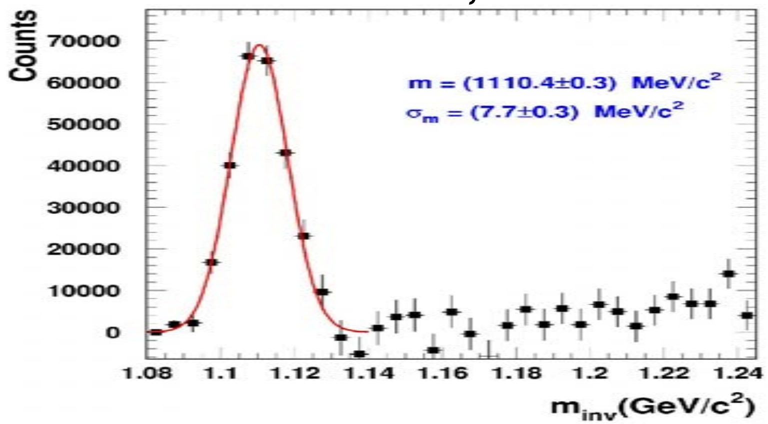


Monte Carlo

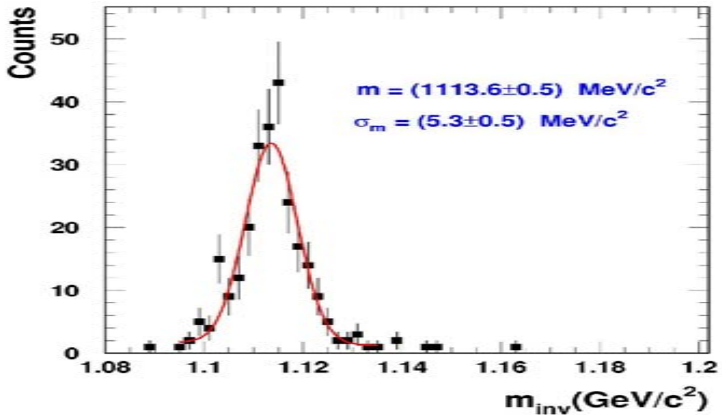


K^0_S

Pb+Au in 2000, 930 k events



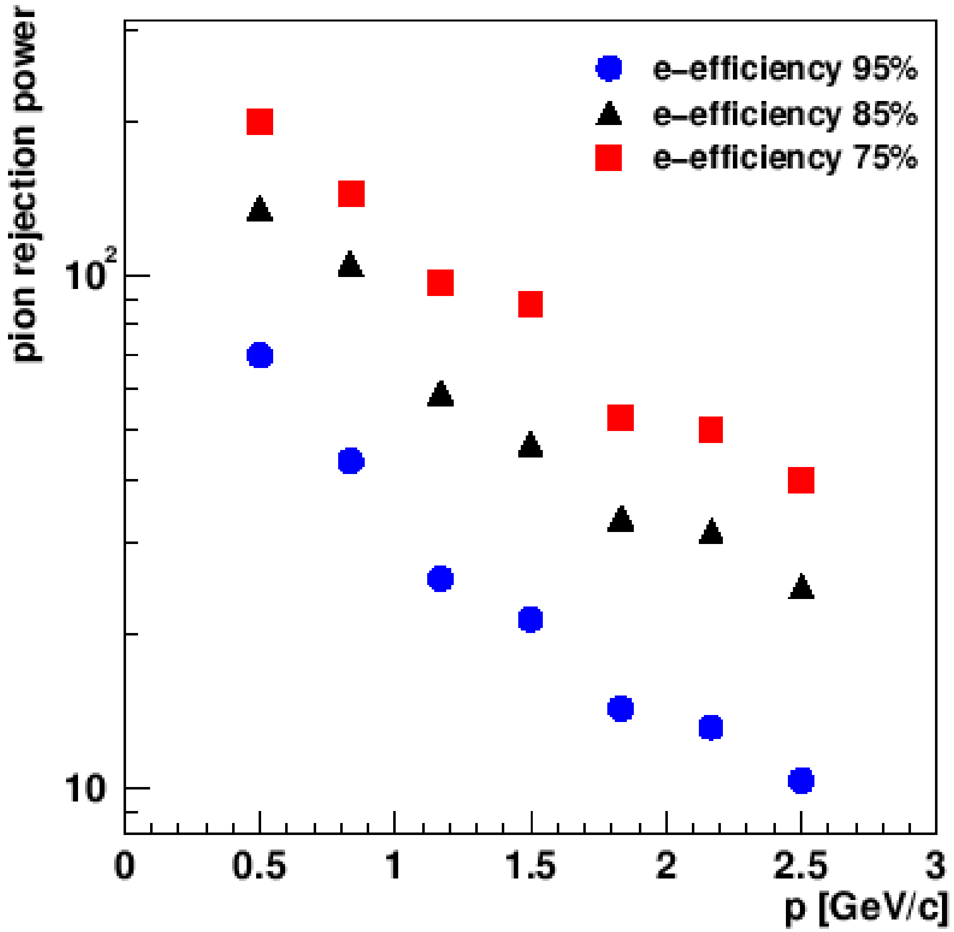
Monte Carlo



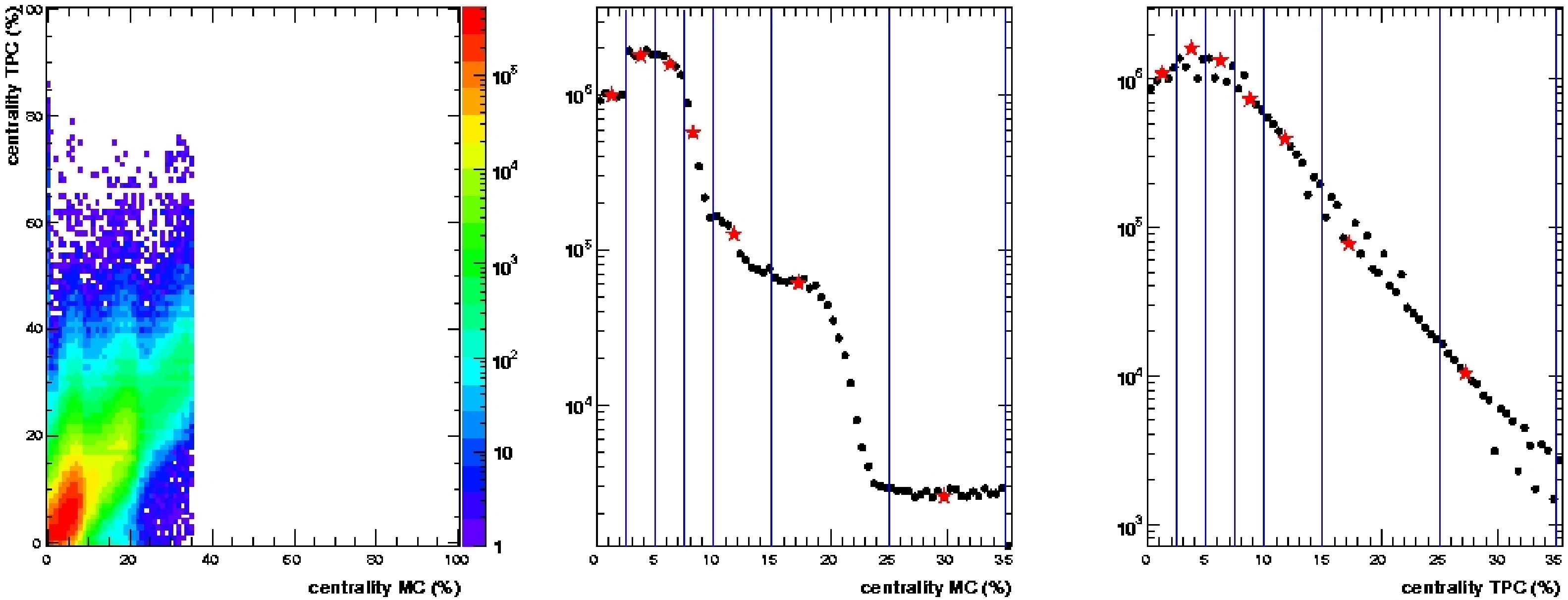
Λ

Compare to the widths in 1999: lambda 12.6 MeV, K0 21.7 MeV

TPC contribution to pid (via dE/dx)

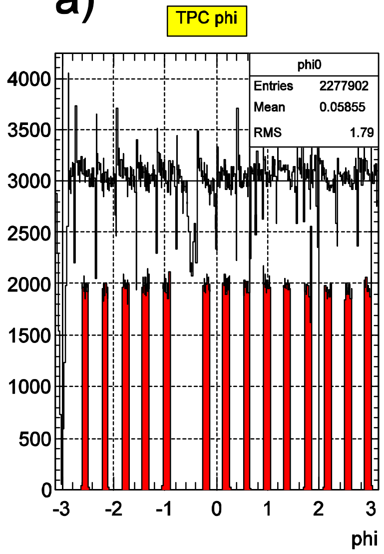


centrality of the analyzed data set

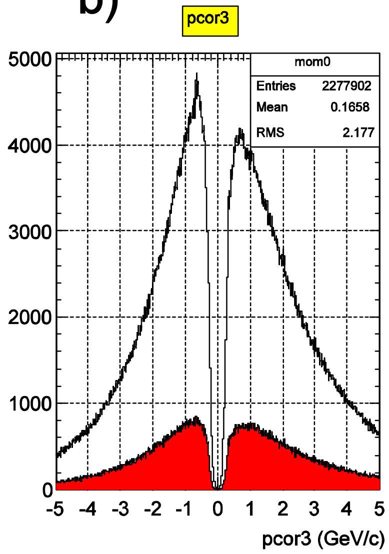


Track multiplicity in the TPC

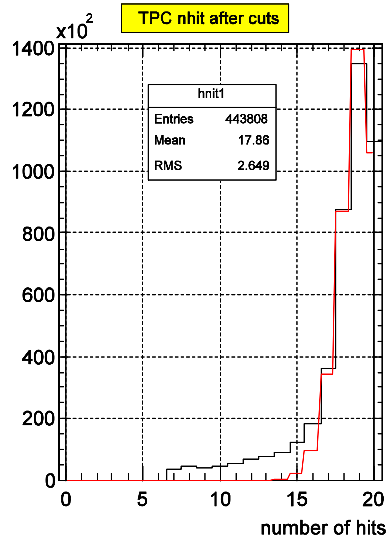
a)



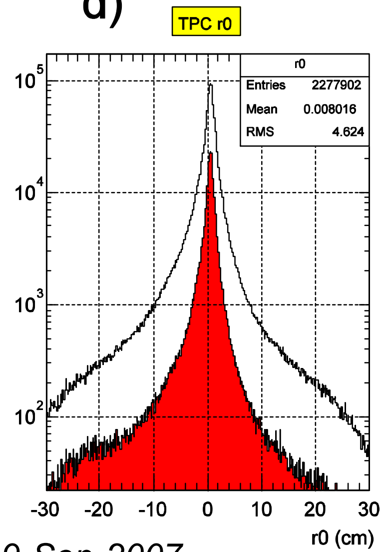
b)



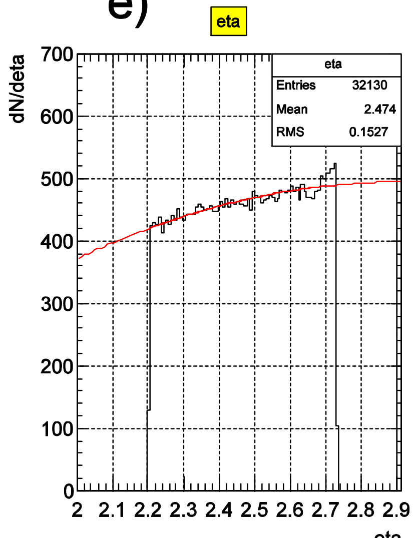
c)

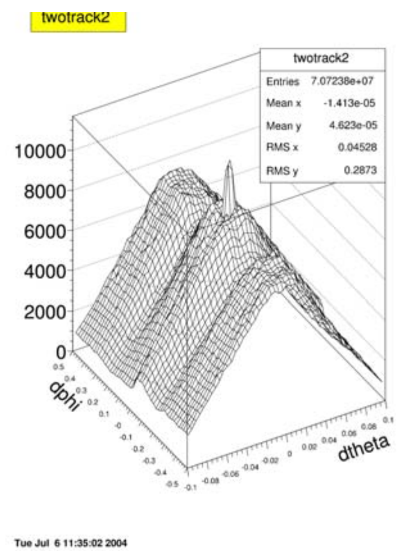


d)

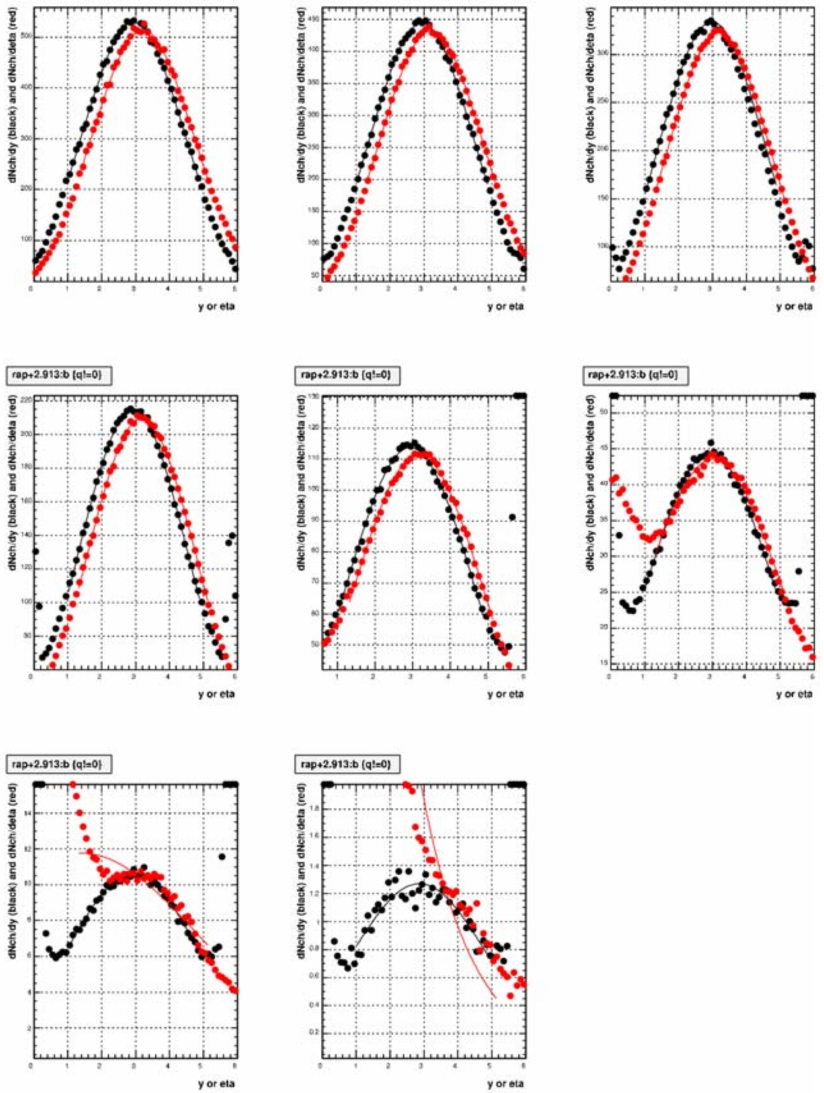


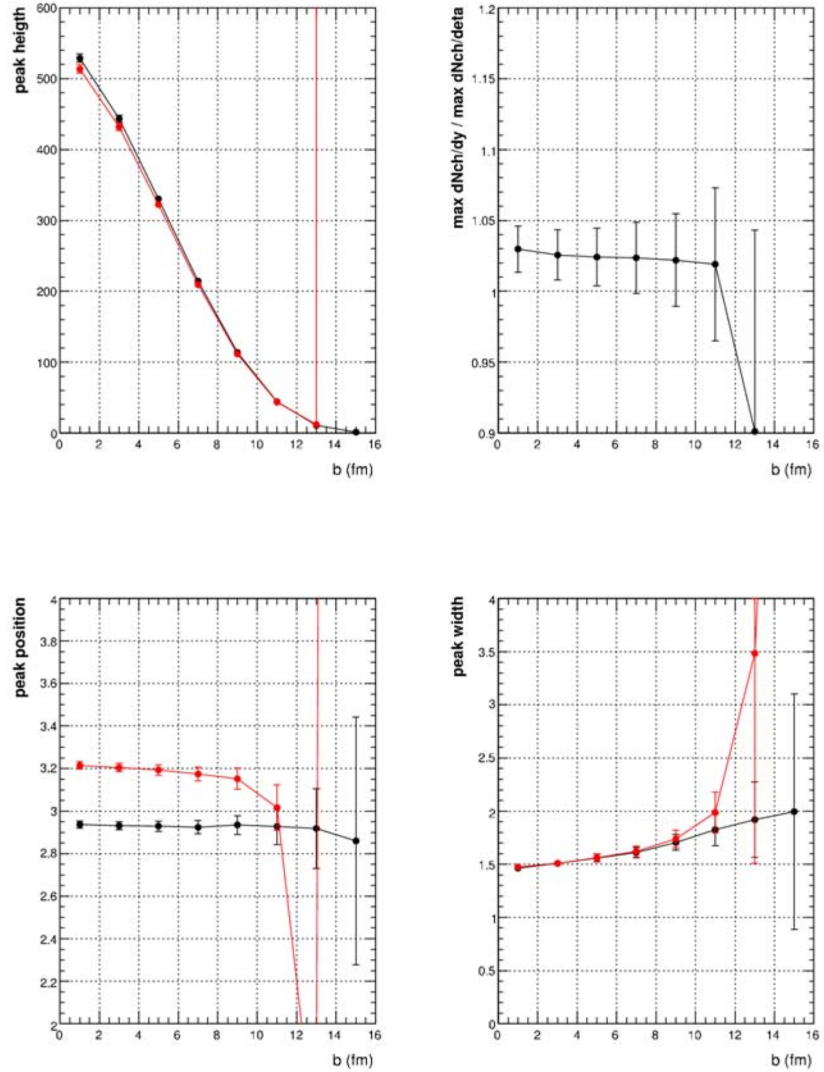
e)





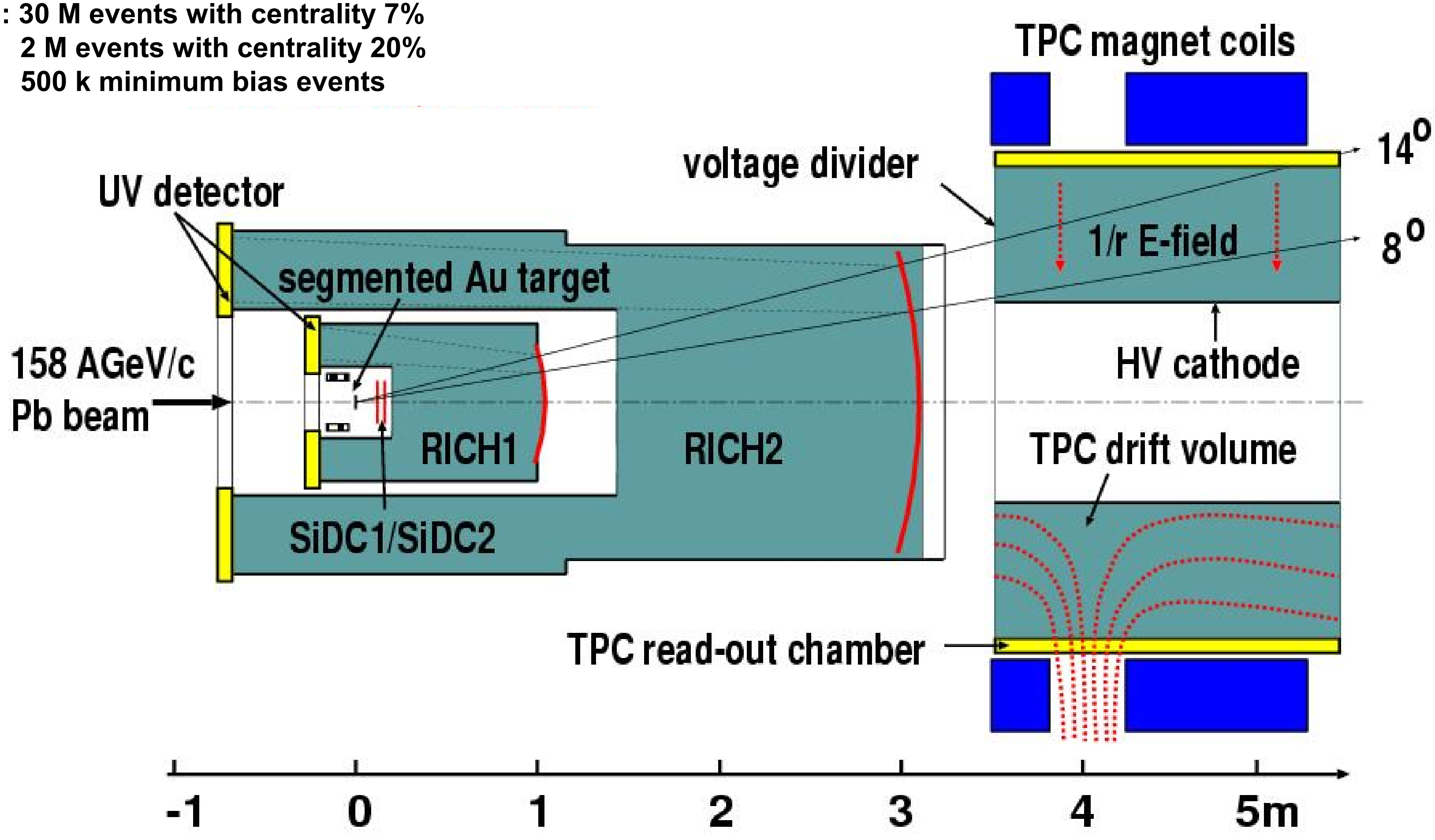
URQMD


dNch/dy (black) and dNch/deta (red)
y or eta
rap+2.913:b {q!=0}


peak heigth
max dNch/dy / max dNch/deta
peak position
peak width
b (fm)

CERES setup in 2000

run 2000: 30 M events with centrality 7%
2 M events with centrality 20%
500 k minimum bias events



Is rho-modification interesting?

At high density and/or temperature chiral condensate disappears

$\rightarrow$ meson masses change

quarks interact with chiral condensate

↓

quarks acquire constituent mass

↓

hadrons acquire mass

↓

mass of macroscopic objects

GENESIS

$$dN/dy \sim \cosh^{-2}[0.75/\sigma(y-y_o)]$$

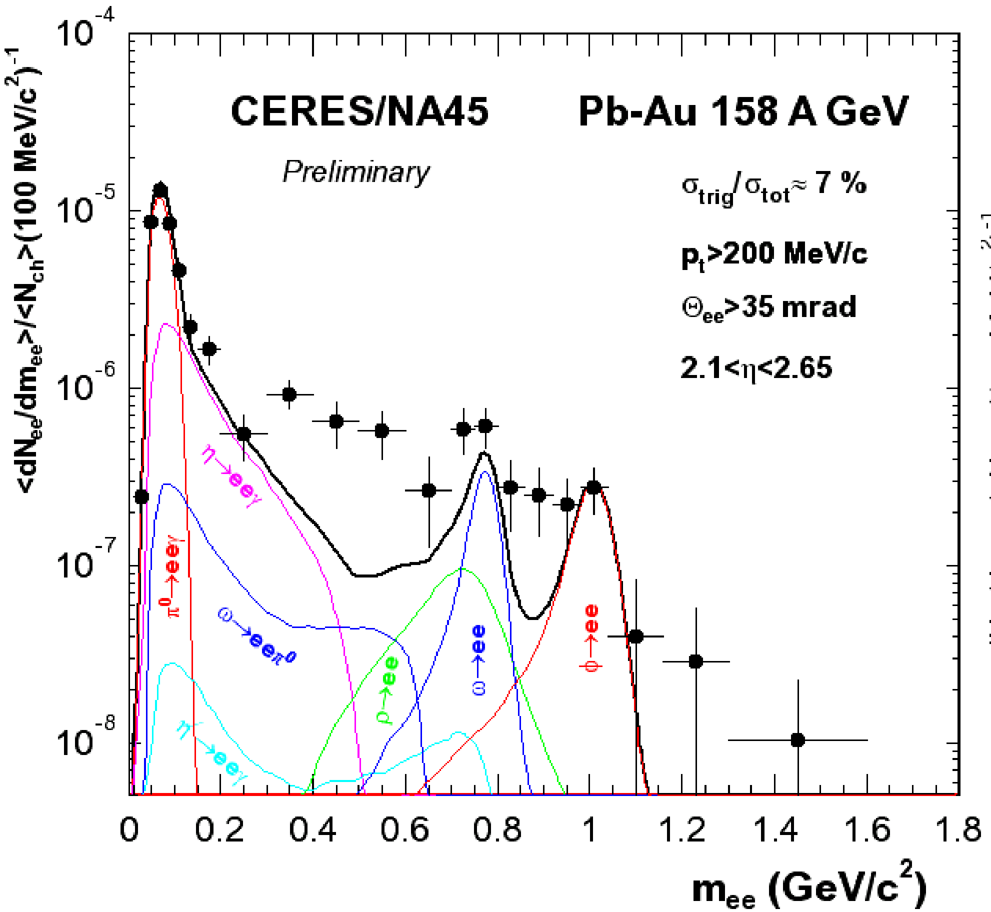
$$dN/dp_t \sim Ae^{-Bm_t} + C(1-0.0682\, m_t)^{7.9}/(1+m_t^2)^4$$

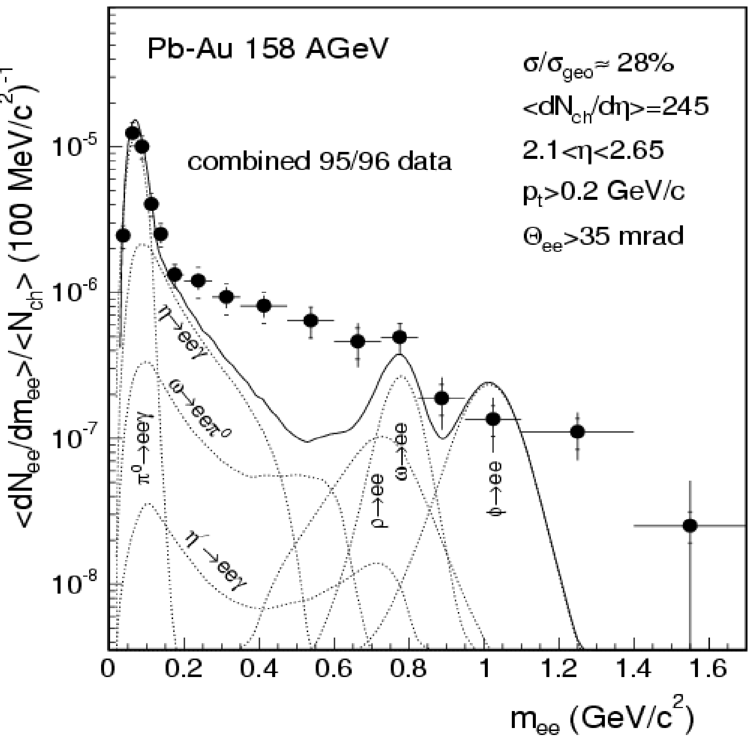
particle	relative abundance	decays
π^o	1.0	$\pi^o \rightarrow \gamma e^+e^-$
η	0.053	$\eta \rightarrow \gamma e^+e^-$
η'	0.009	$\eta' \rightarrow \gamma e^+e^-$
φ	0.0033	$\varphi \rightarrow e^+e^-$
ρ	0.065	$\rho \rightarrow e^+e^-$
ω	0.065	$\omega \rightarrow e^+e^-$ $\omega \rightarrow \gamma e^+e^-$

comparison to the 95/96 data

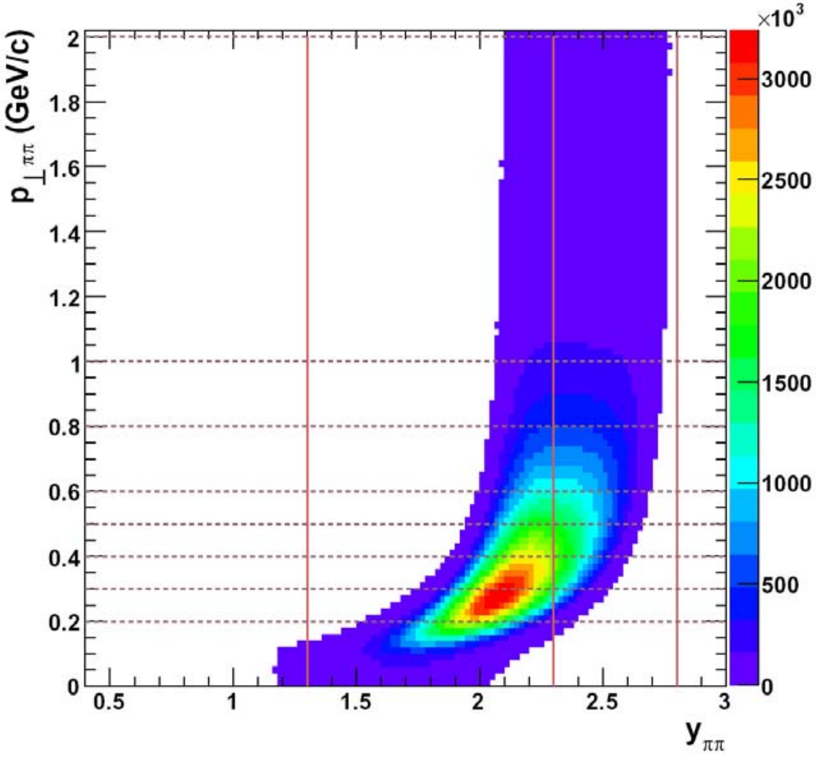
Pb+Au at 158 GeV per nucleon

2000 data:
Sergey Yurevich, Heidelberg

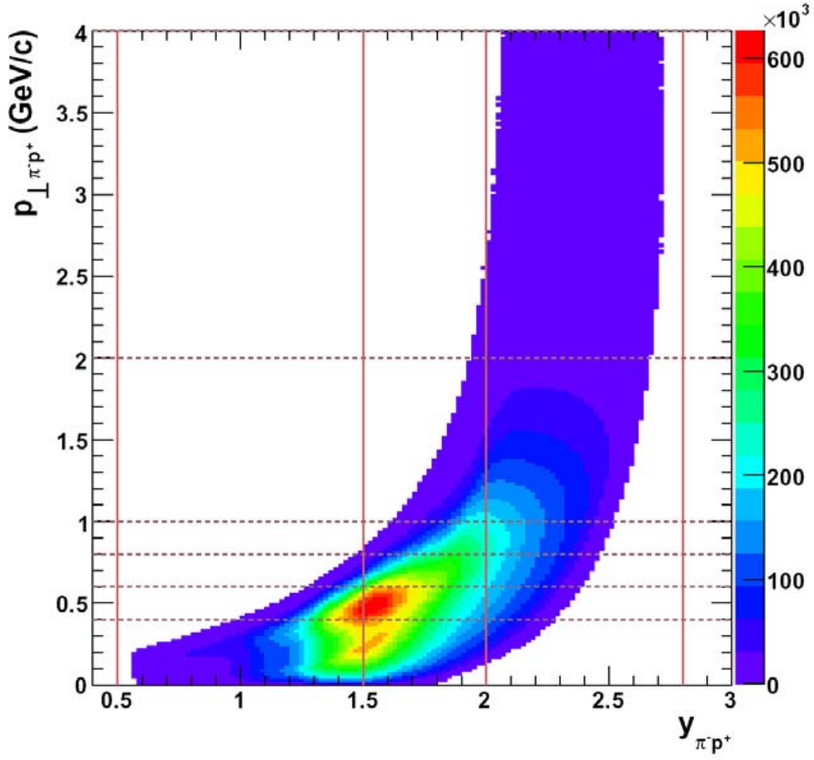




Pair acceptance



midrapidity: y=2.91

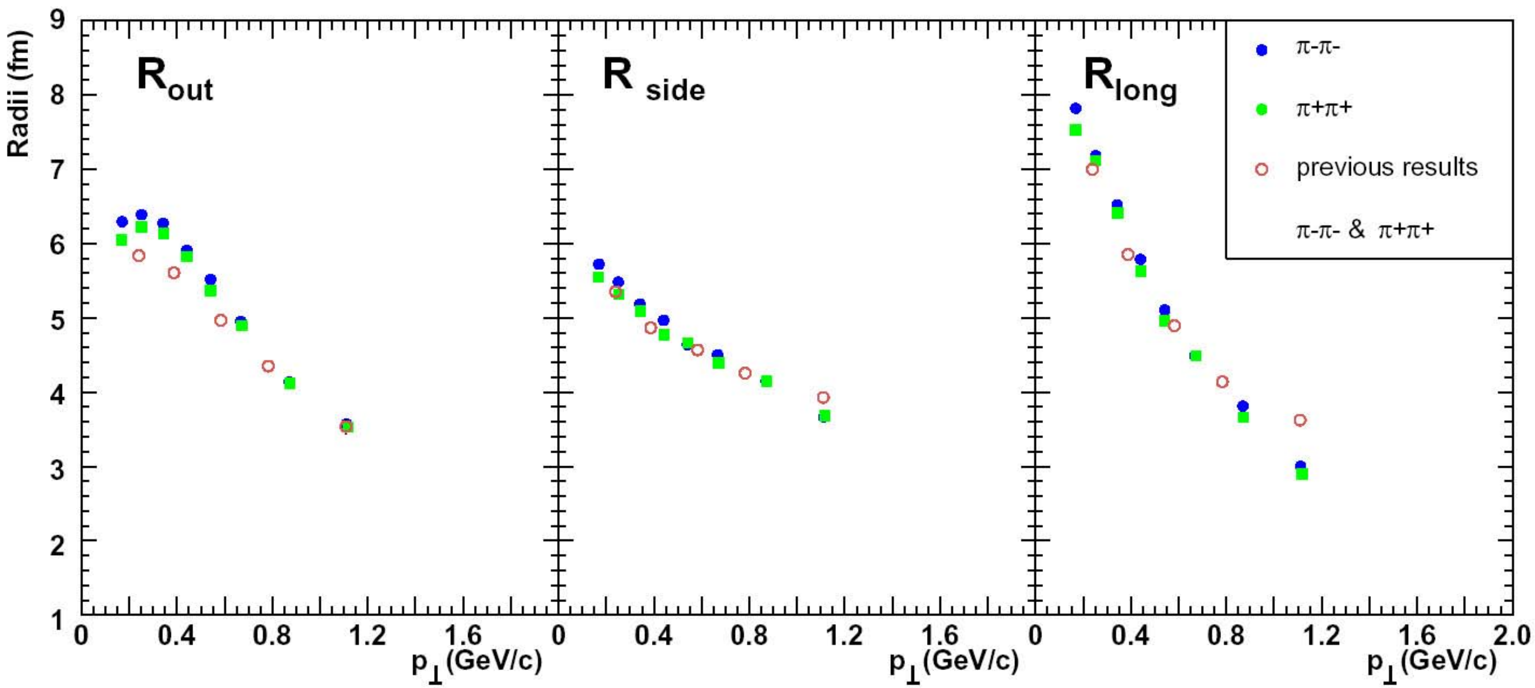


midrapidity

HBT radii: pt dependence

Pb+Au at 158 AGeV
centrality 5%

D. Antonczyk



good agreement with the first analysis

Pion-proton correlations

pair c.m.s.

$q = p_{proton} - p_{pion}$

$C(q_{||}, q_{\perp})$

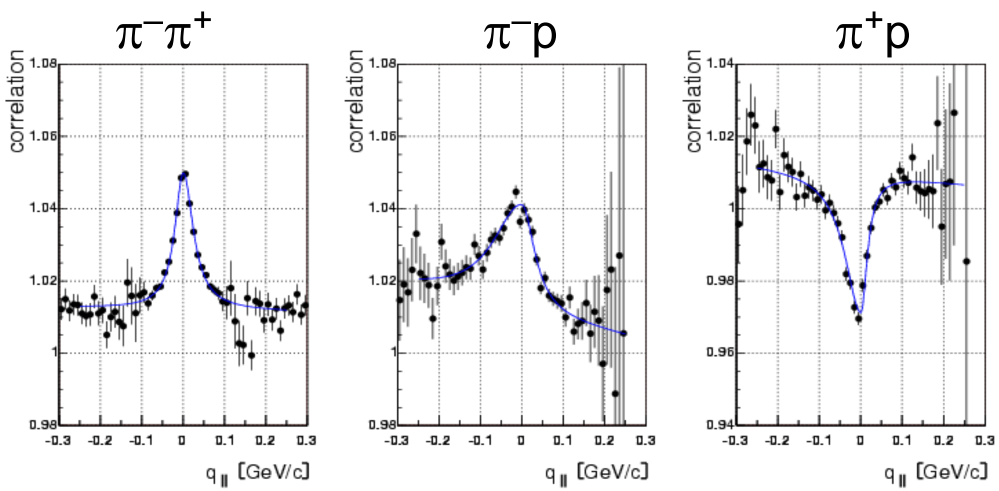
$q_{||}$ is the component parallel to the pair $P_{\perp}$

pion-proton correlations

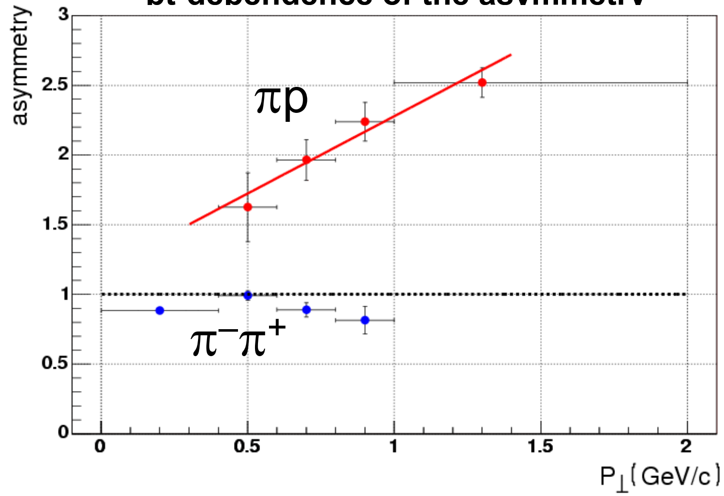
central Pb+Au at 158 AGeV

Dariusz Antonczyk

pion-proton correlation functions



pt-dependence of the asymmetry



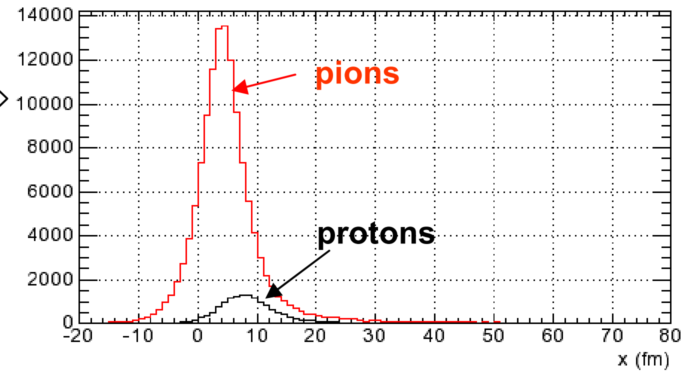
asymmetry of correlation function is related to the asymmetry of the relative source distribution (Lednicky, Phys.Lett.B373(96)30)

proton source at larger transverse radius than pion source (or earlier emission)

most probable origin: transverse flow

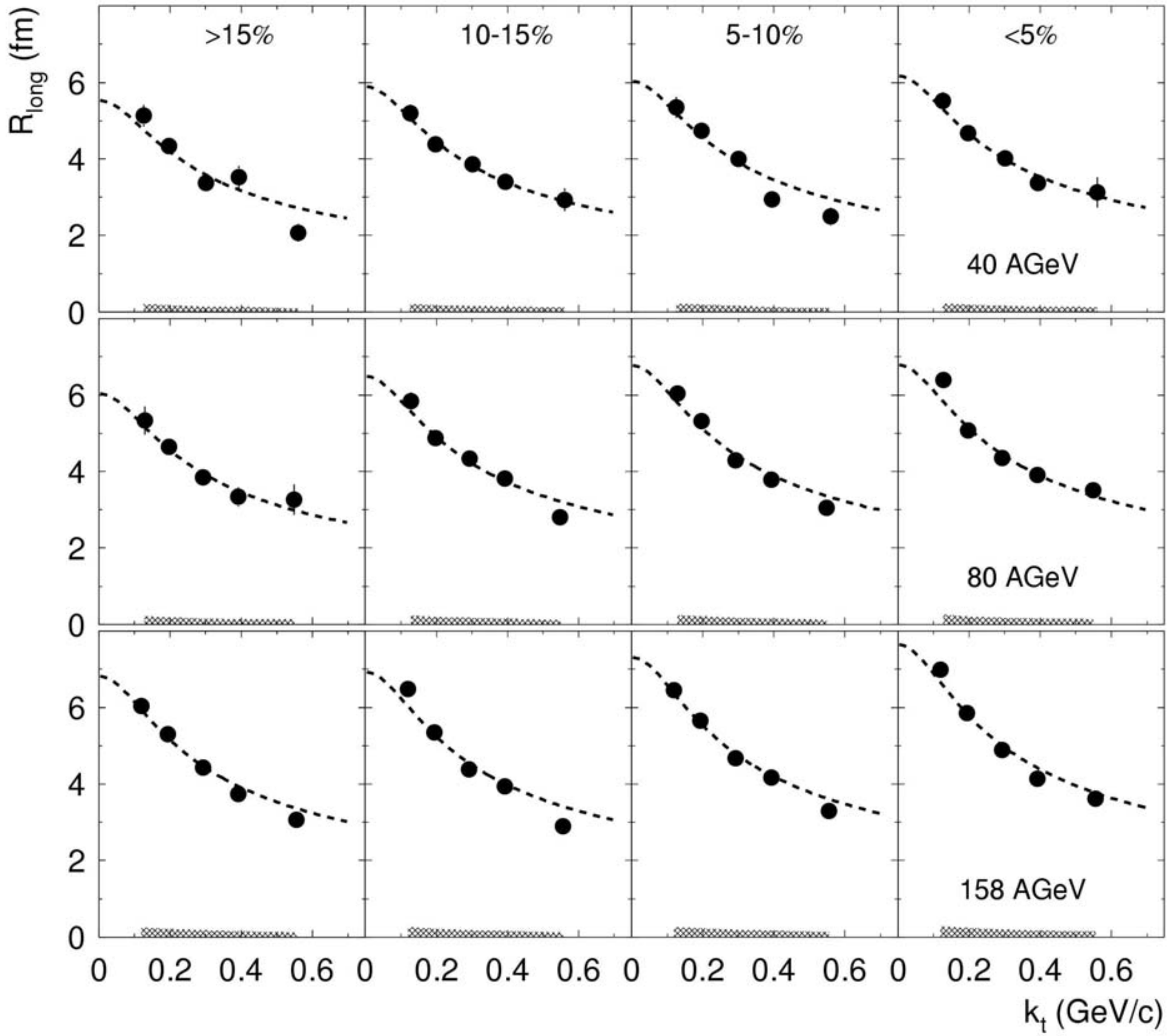
sensitive to the details of reaction dynamics

pion and proton sources in UrQMD

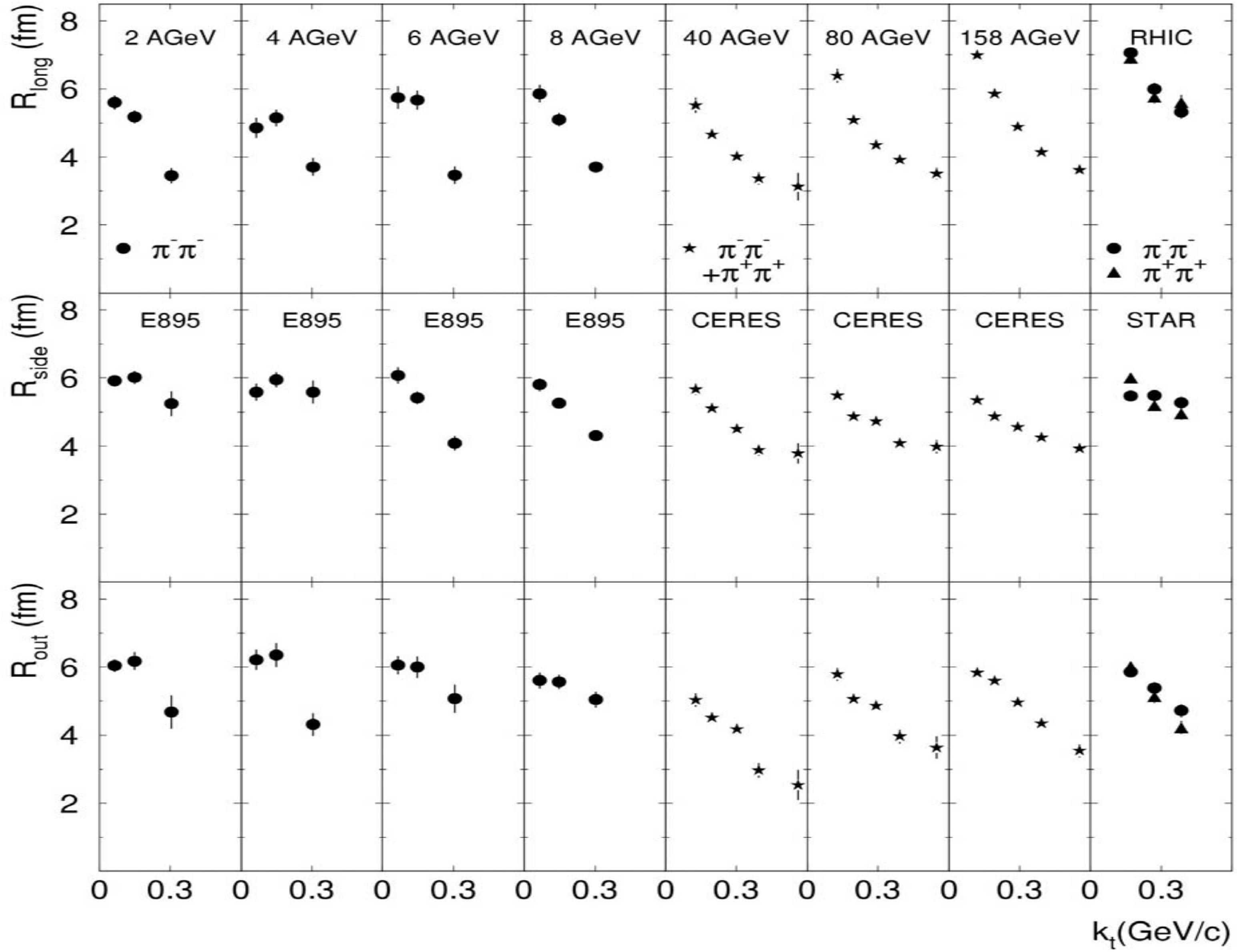


First HBT results with upgraded CERES

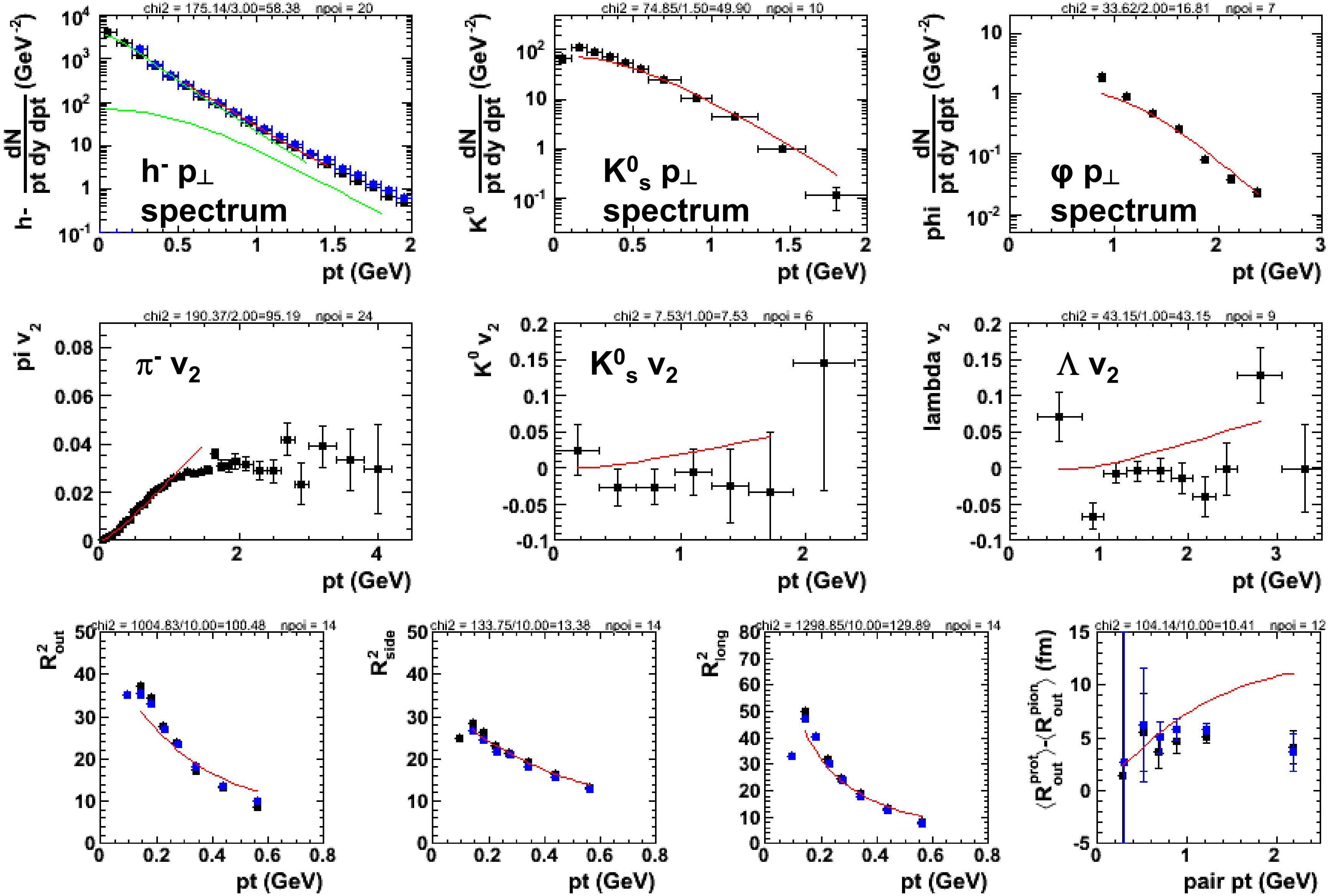
analysis by Heinz Tilsner and Harry Appelshäuser
centrality and energy dependence



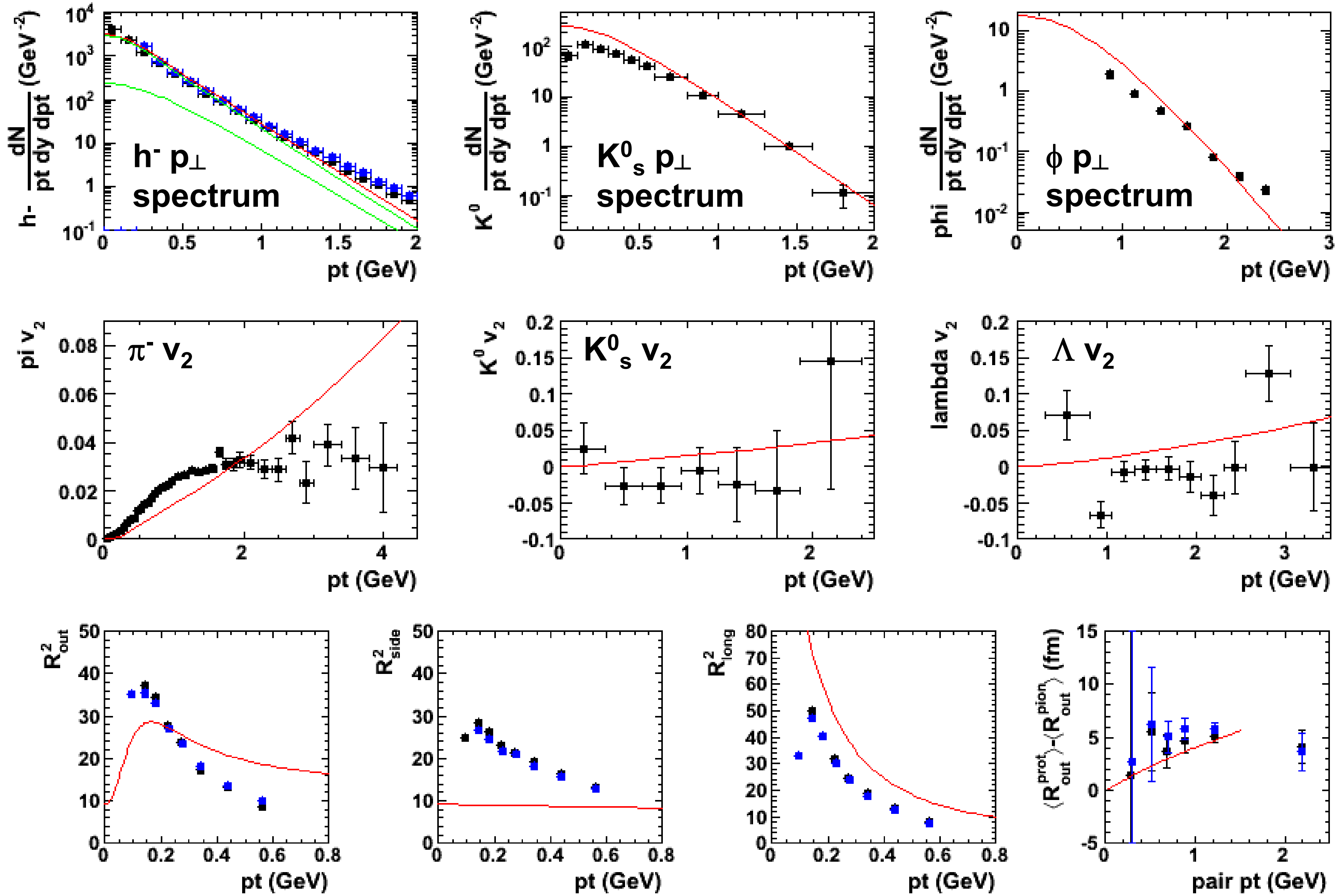
analysis by Heinz Tilsner and Harry Appelshäuser



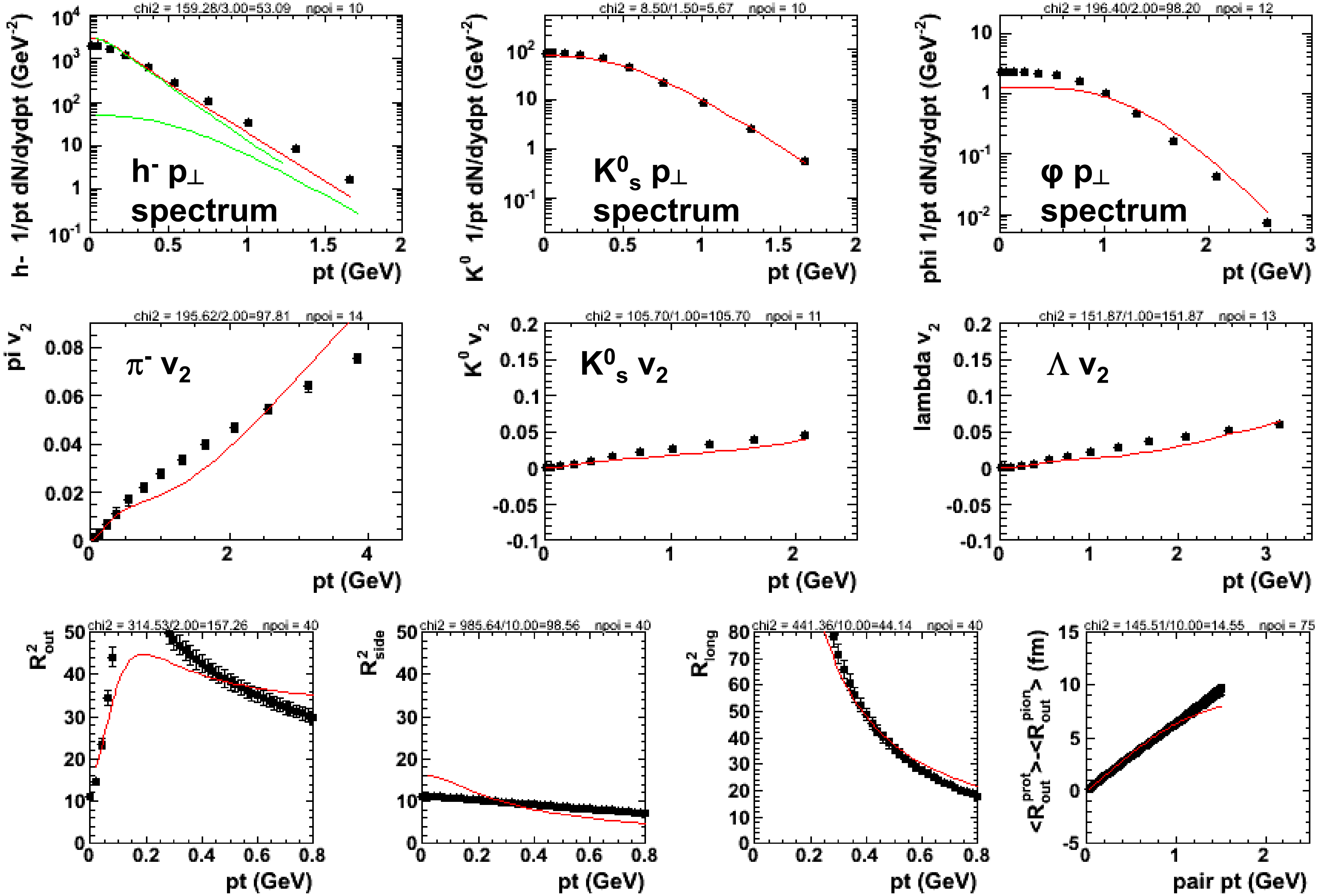
CERES (points) and blast T=80 MeV (lines)



CERES (points) and hydro T=160 MeV (lines)



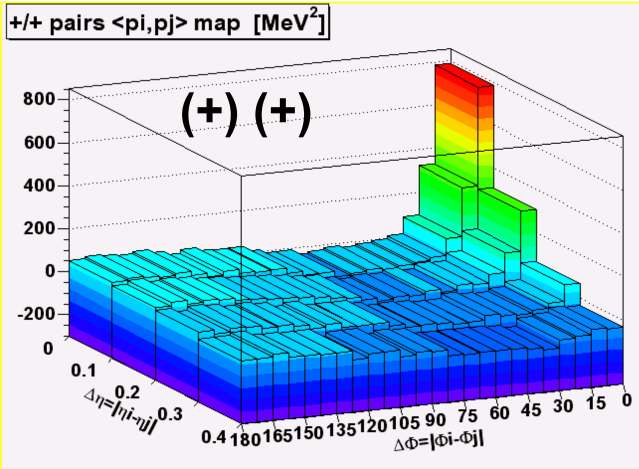
hydro 120 MeV (points) and blast (lines)

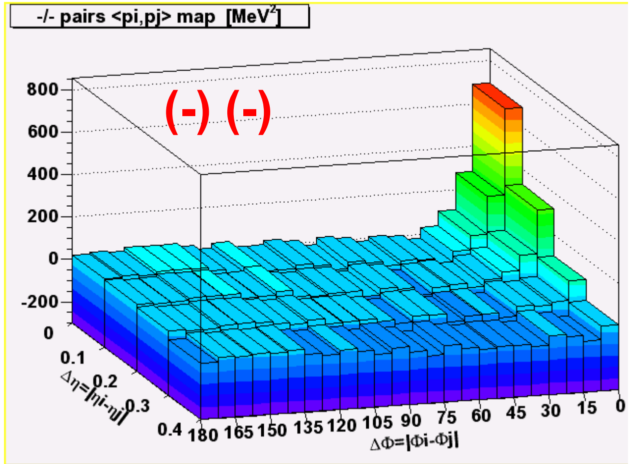


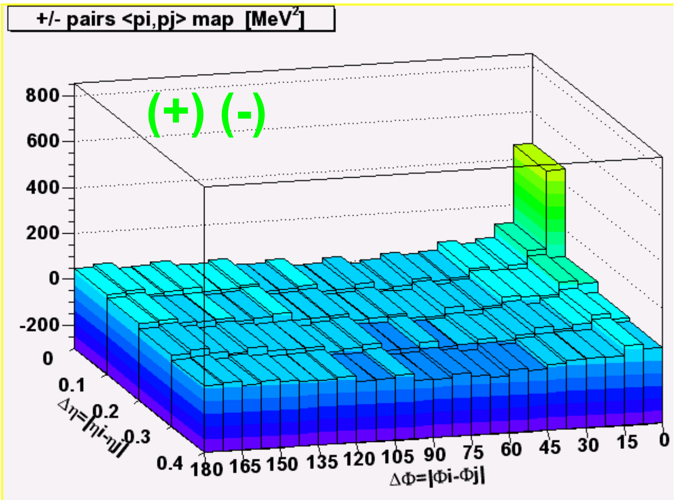
pt fluctuations, charge dependence

Pb+Au at 158 GeV per nucleon

G. Tsiledakis, GSI Darmstadt







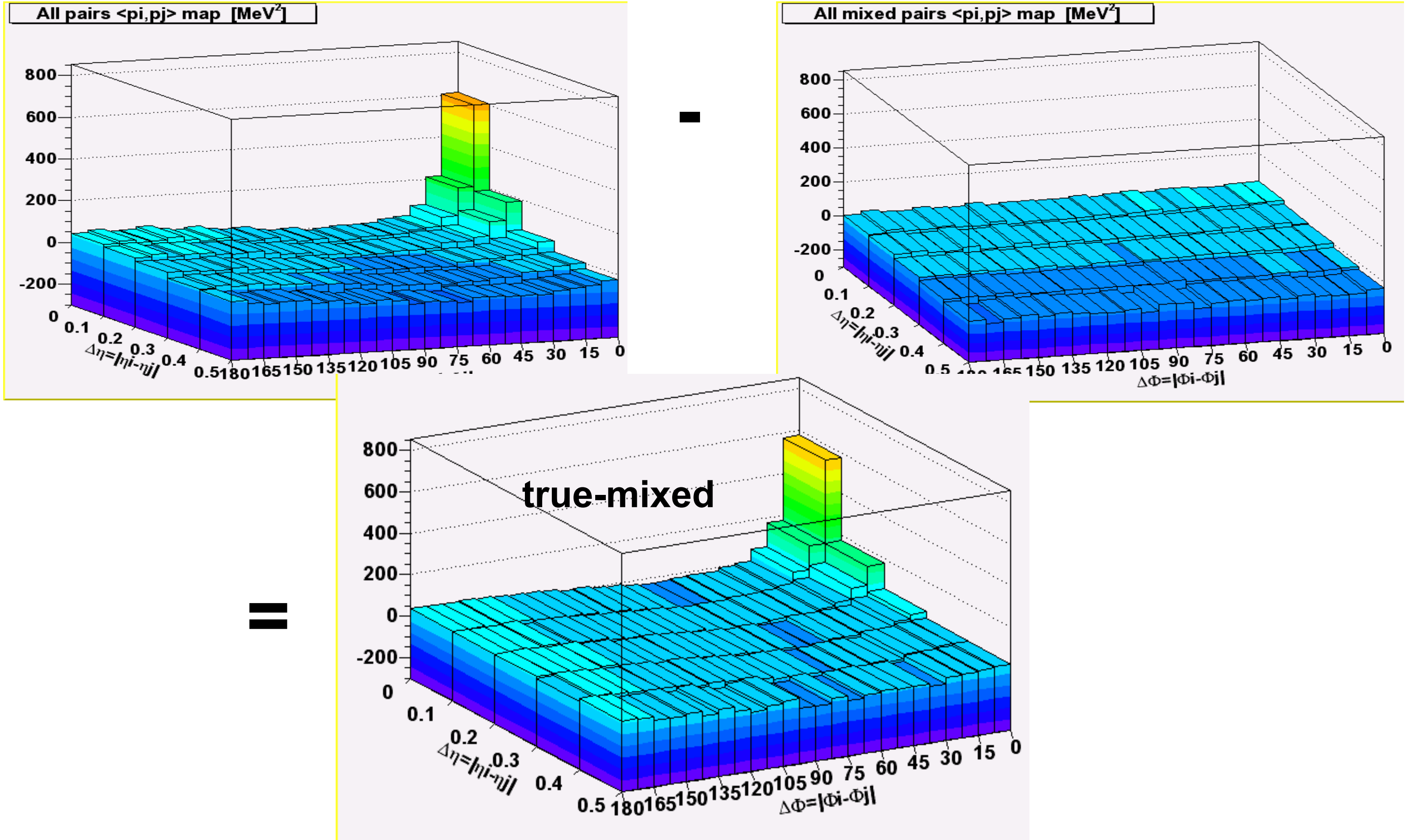
pt fluctuations, event mixing

Pb+Au at 158 GeV per nucleon

G. Tsiledakis, GSI Darmstadt

true pairs

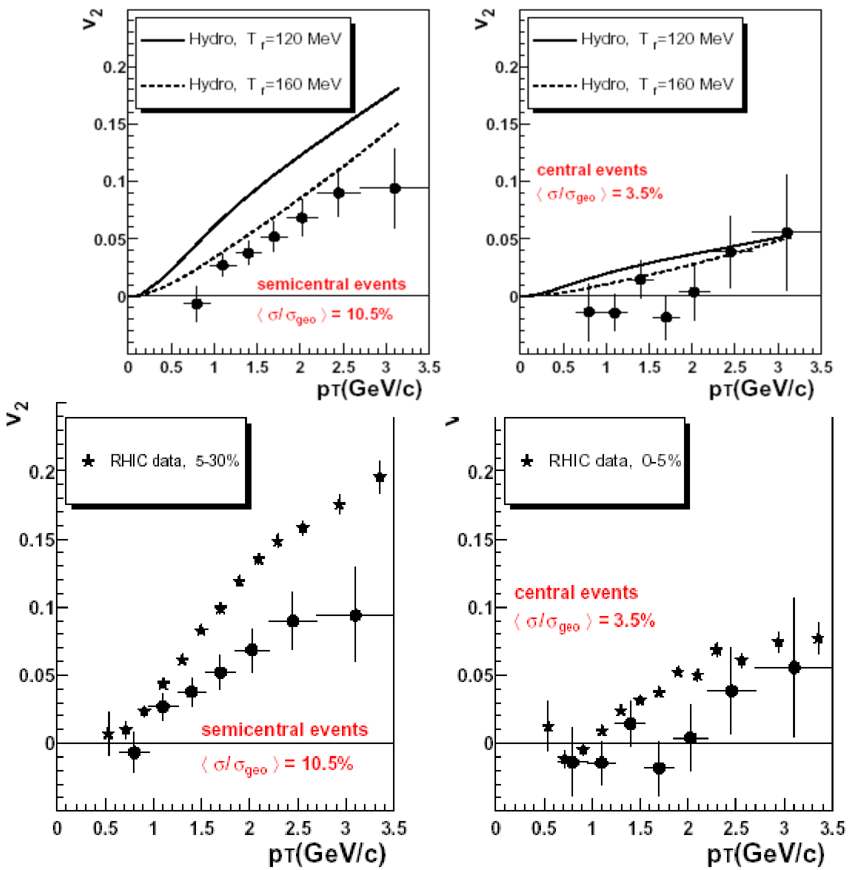
mixed



Λ flow

Pb+Au at 158 GeV per nucleon

Jovan Milosevic



comparison with hydro (P. Huovinen):

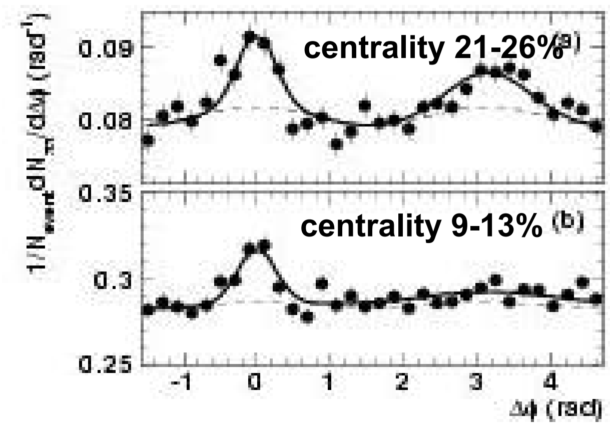
calculation with T=160 MeV describes the Λ and π flow

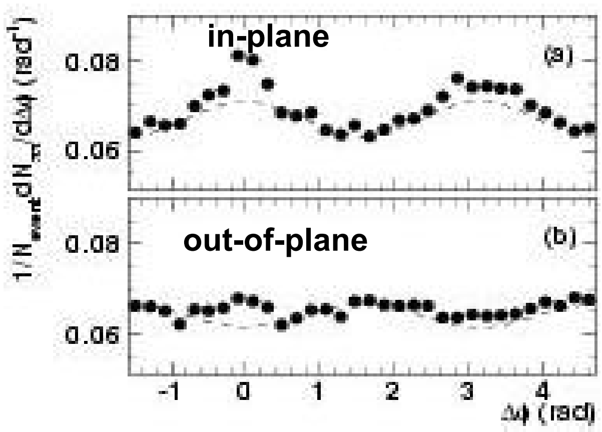
comparison with STAR PRL 92(2004)052302:

similar pt dependence about 60% in magnitude

angular correlations of high-pt particles

Pb+Au at 158 GeV per nucleon





J. Bielcikova, 1996 data
PRL 92 (2004) 032301