NA49 and NA61/SHINE experiments: results and plans

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For NA49 and NA61/SHINE collaborations

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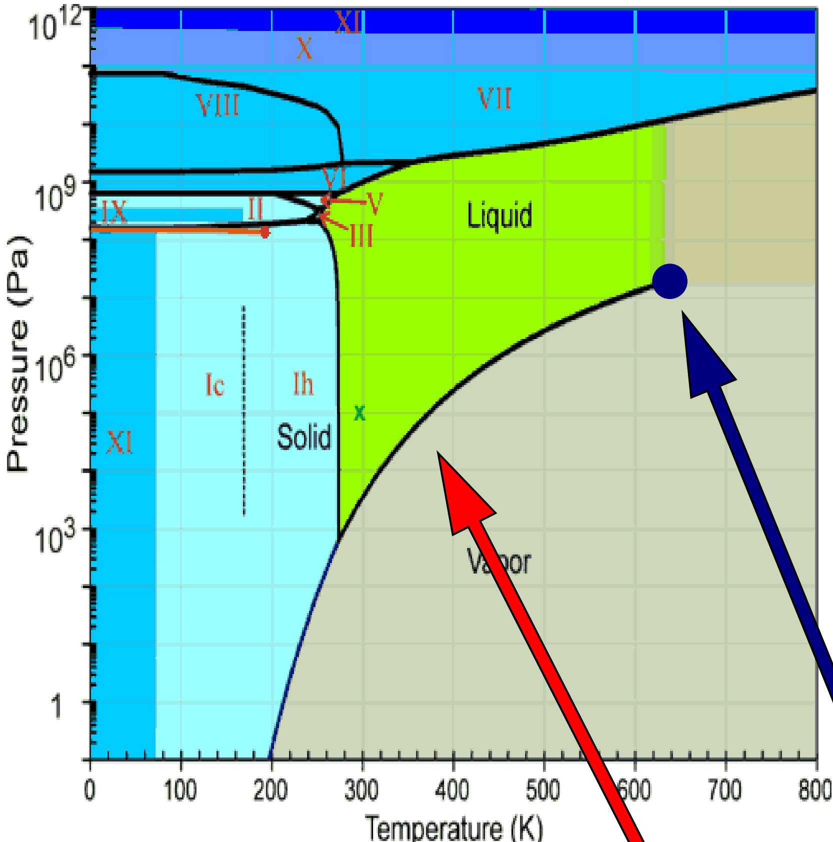
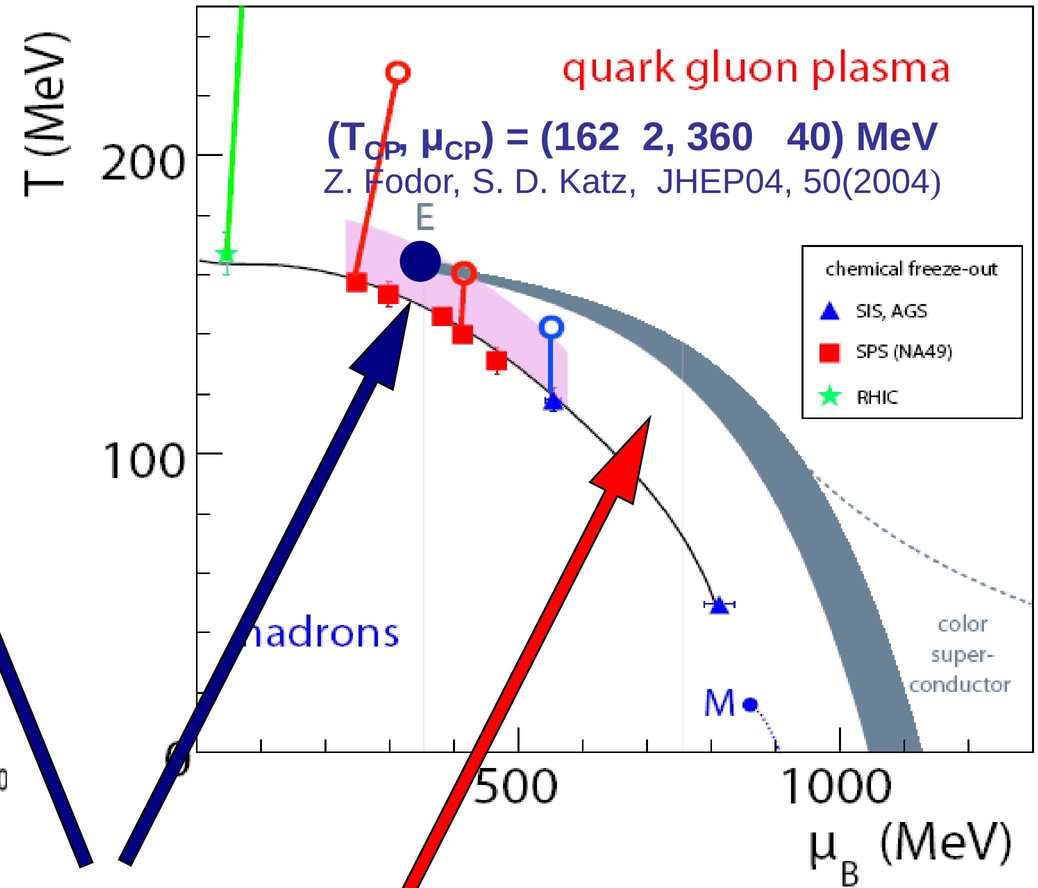
Phase diagram of strongly interacting matter

water

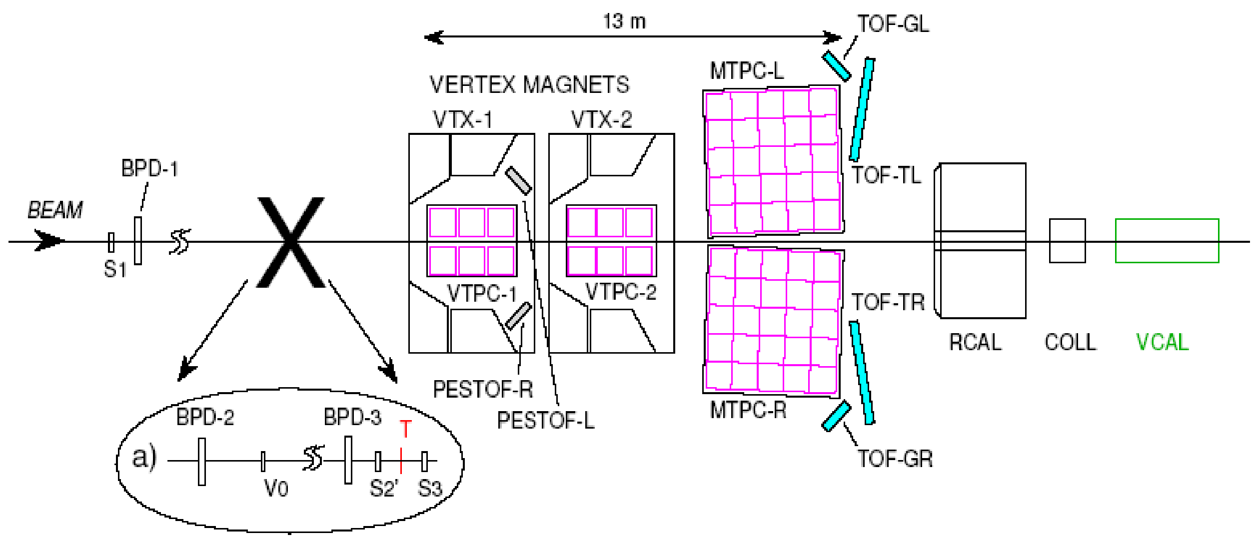


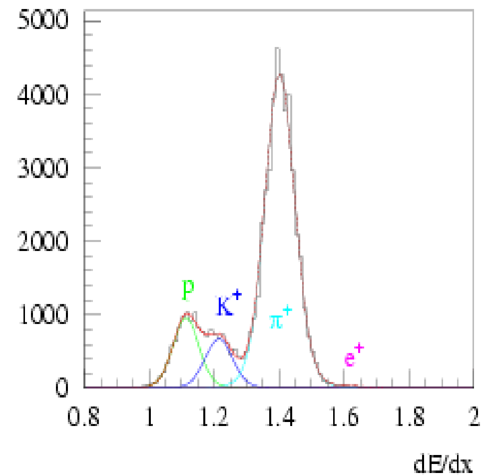
strongly interacting matter



critical point

1st order phase transition

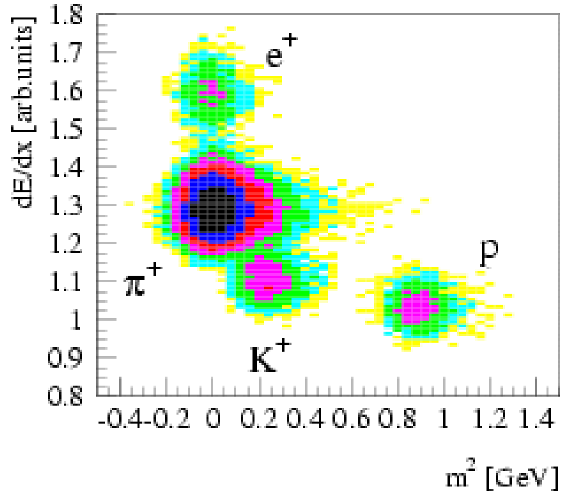




PID by dE/dx

- Large acceptance hadron detector
- Tracking by large volume TPC (VTPC1 & VTPC2 inside magnets)
- PID by dE/dx, TOF, decay topology, invariant mass
- Centrality determination by Forward Calorimeter (energy of projectile spectators)

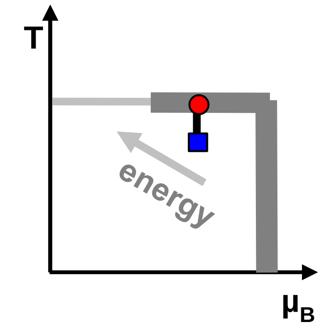
- Data taking 1994 -2002
- Data sets: p+p, C+C, Si+Si, Pb+Pb



PID by TOF + dE/dx

Evidence for the onset of deconfinement

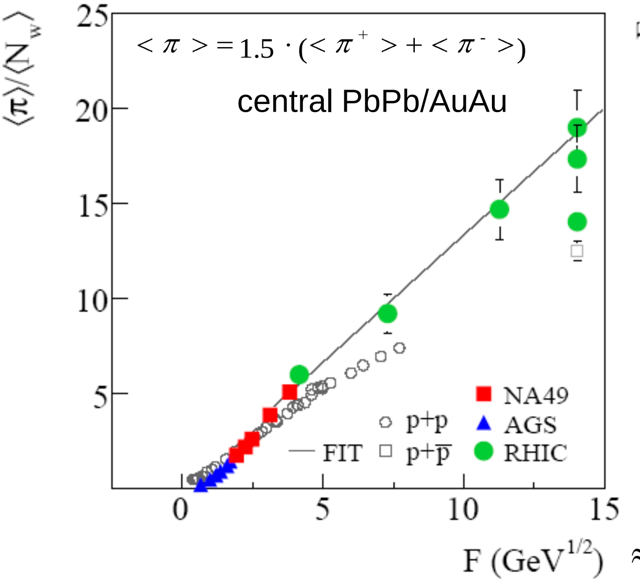
Onset of Deconfinement: early stage hits transition line, predicted & observed signals: kink, horn, step



SMES model, M.Gazdzicki and M.Gorenstein, Acta Phys. Pol.30,2705(1999)
M.Gazdzicki et al.,arXiv:1006.1765

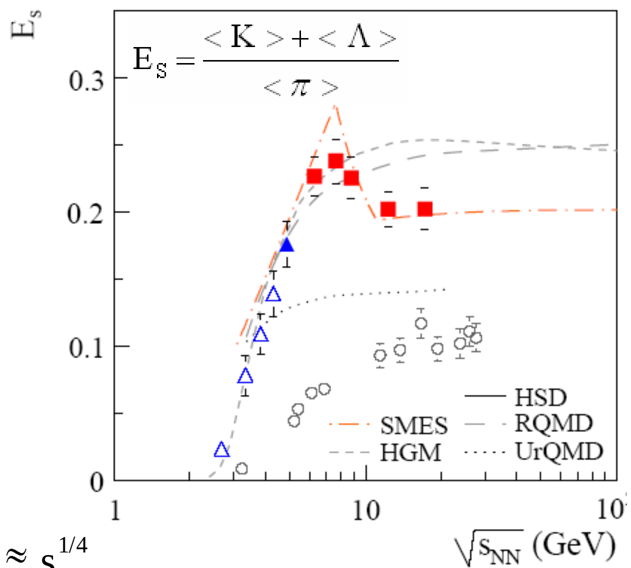
the kink

pion yield per participant



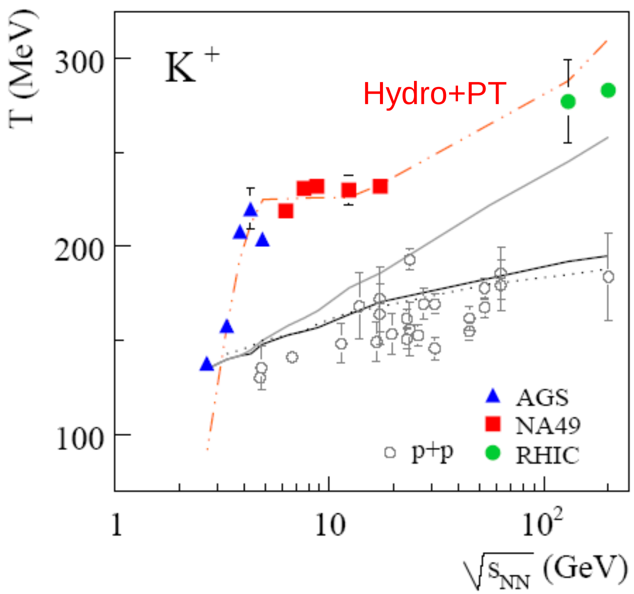
the horn

ratio of strange particle to pion yield



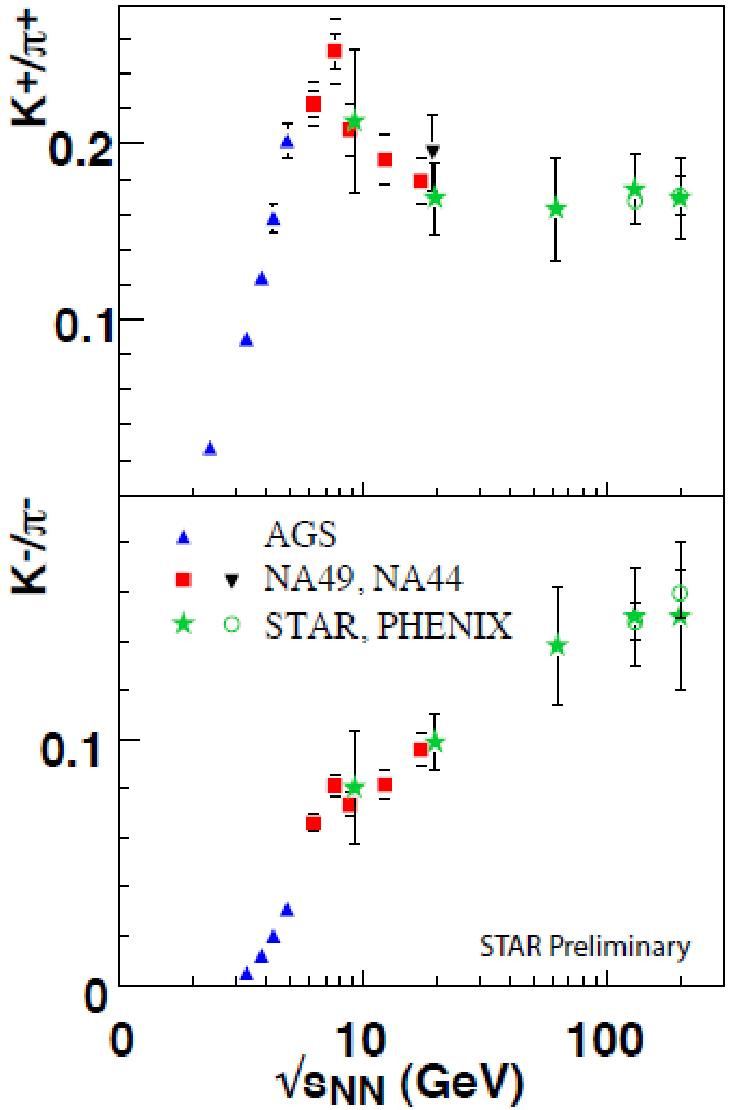
the step

shape of transverse mass spectra



NA49,C.Alt et al.,PRC77,024903(2008)

Comparison with STAR results



Search for the critical point

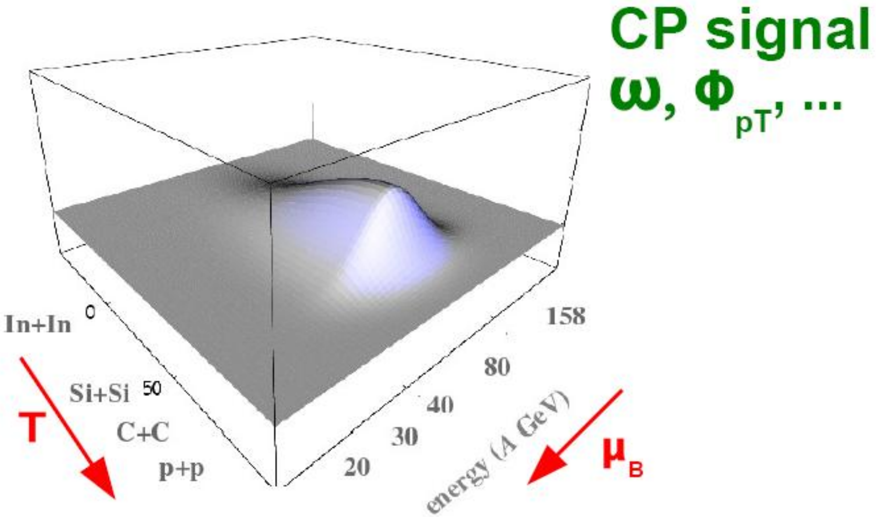
Predicted signals

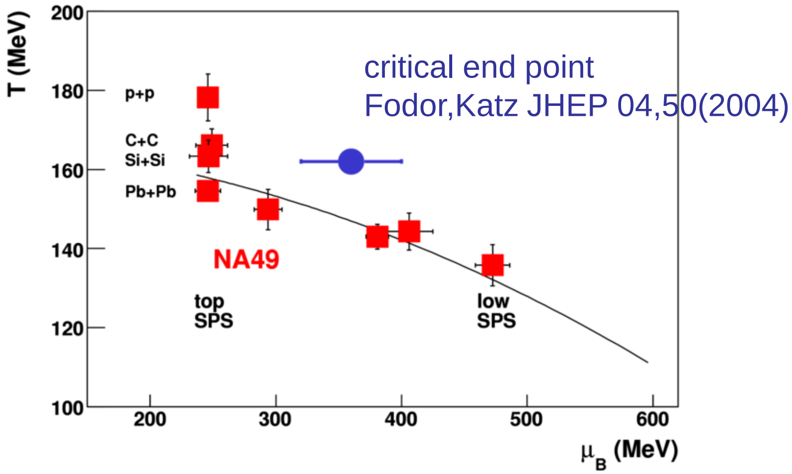
- enhanced fluctuations of multiplicity, p_T, …
- expected size of fluctuation signals limited by finite lifetime and size of collision system (correlation lengths ~ 3 – 6 fm))

Conditions

- system has to reach deconfinement
- freeze-out occurs close to the critical point

M.Stephanov, K.Rajagopal,E.Shuryak, PRD60,114028(1999)





Strategy

Search for the "hill" in fluctuation signals in 2D scan (T,μ_B) of phase diagram

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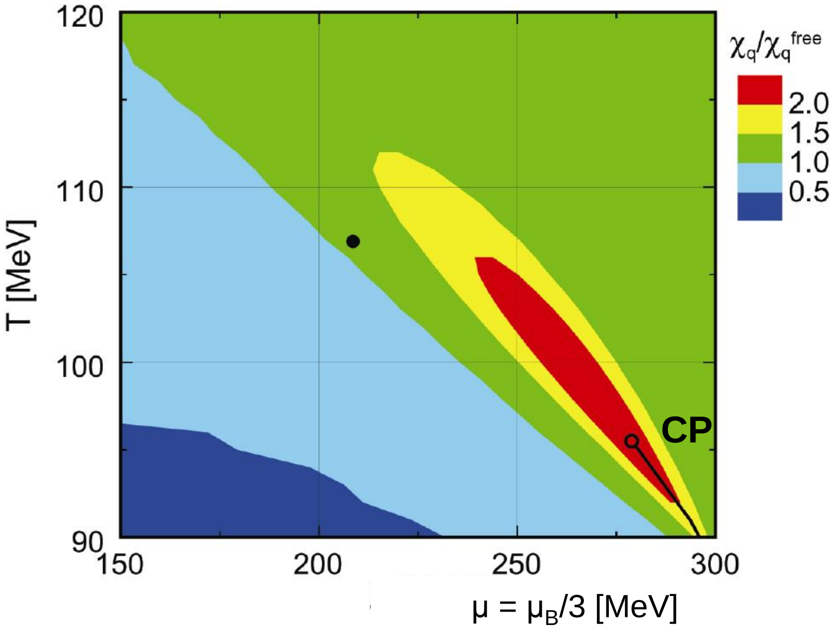
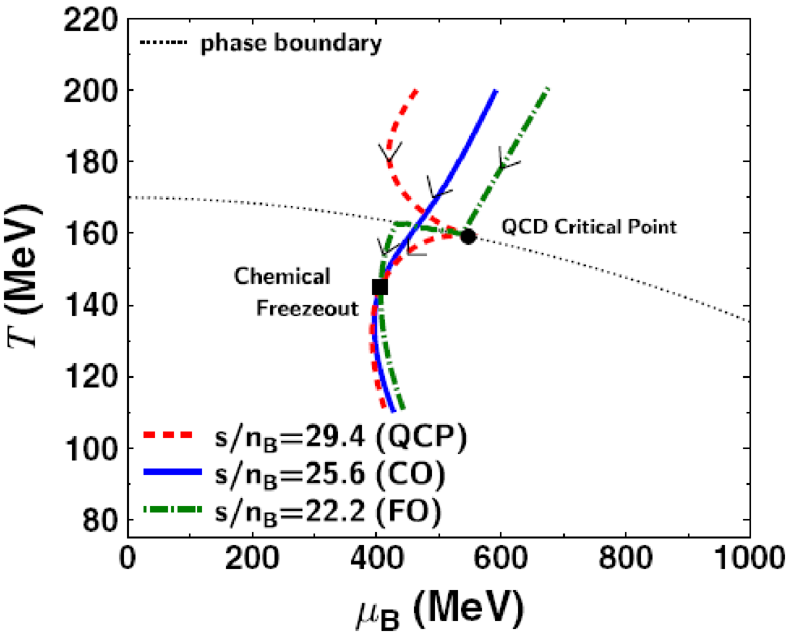
Search for the critical point

effects of critical point are expected over a range of T,μ_B



Y.Hatta and T.Ikeda, PRD67,014028 (2003)

hydro predicts that evolution of the system is attracted to critical point



M.Asakawa et al., PRL 101,122302 (2008)

Not necessary to hit precisely the critical point because large region can be affected

Fluctuation measures

ω: scaled variance of the multiplicity distribution

$$\omega = \frac{\mathrm{Var(n)}}{\langle n \rangle} = \frac{\langle n^2 \rangle - \langle n \rangle^2}{\langle n \rangle}$$

- superposition model:

  $\omega(A+A)=\omega(N+N)+<n>\omega_{part}$

- ω affected by participant fluctuations
- Poissonian multiplicity distribution: $\omega = 1$

Φ_x: fluctuations of observable x ($<p_{P_T}>$, $<\phi>$, Q,…)

M.Gazdzicki and S.Mrowczyski, Z.Phys.C54,127(1992)

$$\Phi_{\mathrm{x}} = \sqrt{\frac{\langle \mathrm{Z}^2 \rangle}{\langle \mathrm{n} \rangle}} - \sqrt{\bar{\mathrm{z}^2}}$$

$$\mathrm{z} = \mathrm{x} - \bar{\mathrm{x}}, \qquad \mathrm{Z} = \sum_{i=1}^{n} (\mathrm{x_i} - \bar{\mathrm{x}})$$

<…> → averaging over events

\- → inclusive average

- superposition model:

  $\Phi_x(A+A)= \Phi_x(N+N)$

- Φx independent of participant fluctuations
- independent particle emission: $\Phi_x= 0$

σ_{dyn}: measure of particle ratio fluctuations (K/π, p/π, K/p)

$$\sigma_{dyn} = \mathrm{sign}(\sigma^2_{data} - \sigma^2_{mix})\sqrt{|\sigma^2_{data} - \sigma^2_{mix}|}, \quad \sigma^2_{dyn} = |\nu_{dyn}|$$

E-by-E fit of particle multiplicities required

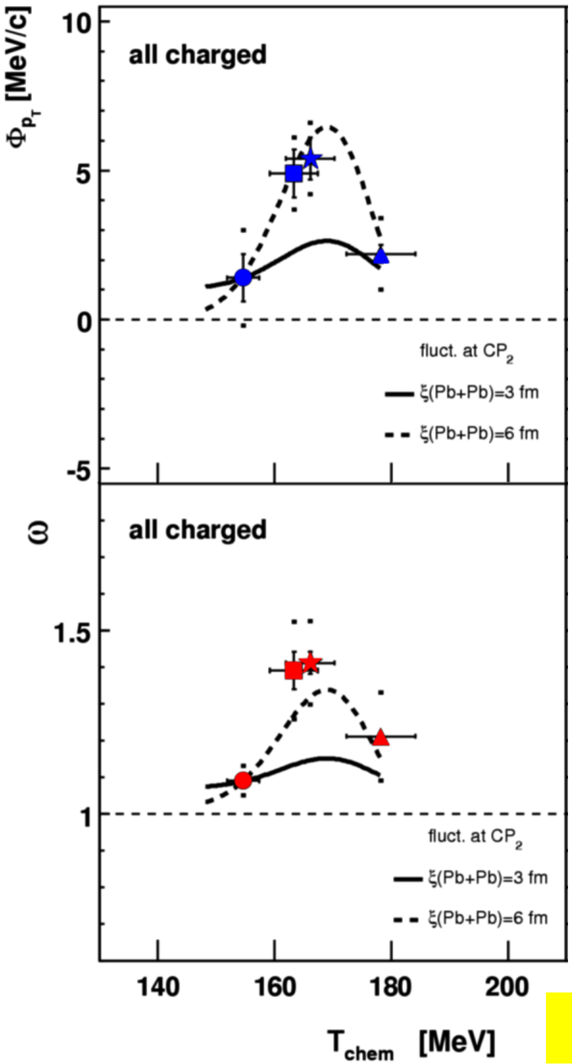
mixed events used as reference

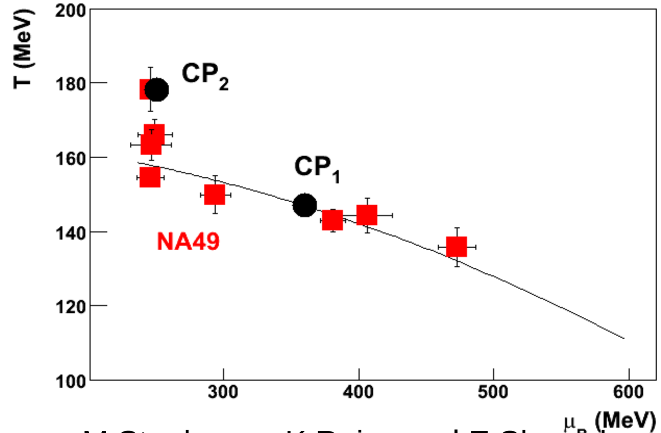
Multiplicity and $\langle p_T \rangle$ fluctuations

T.Anticic et al., PRC70,0234902(2004)
C.Alt et al., PRC75,064904 (2007)

C. Alt et al., PRC78, 034914 (2008)
B. Lungwitz, PhD thesis

system size dependence





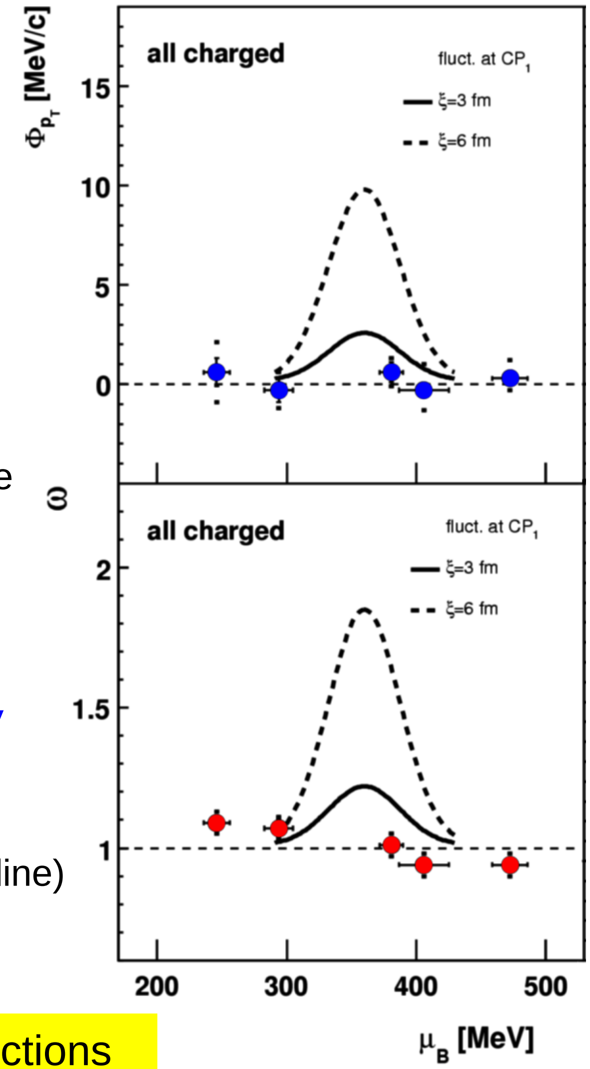
M.Stephanov, K.Rajagopal,E.Shuryak, PRD60,114028(1999)

correlation length ξ limited by finite size and lifetime of the fireball:

ξ(Pb+Pb) = 3 → 6 fm
ξ(p+p) = 1 → 2 fm

range of correlation effect:
$\sigma(\mu_B)$ = 30 MeV, σ(T) = 10 MeV
(Hatta,Ikeda,PRD67,014028(2003)

energy dependence



CP_1 μ_B= 360 MeV (lattice QCD), T = 147 MeV (chem. freeze-out line)

CP_2 μ_B= 250 MeV (data 158A GeV) T = 178 MeV (fit of p+p data)

Data are consistent with CP_2 predictions

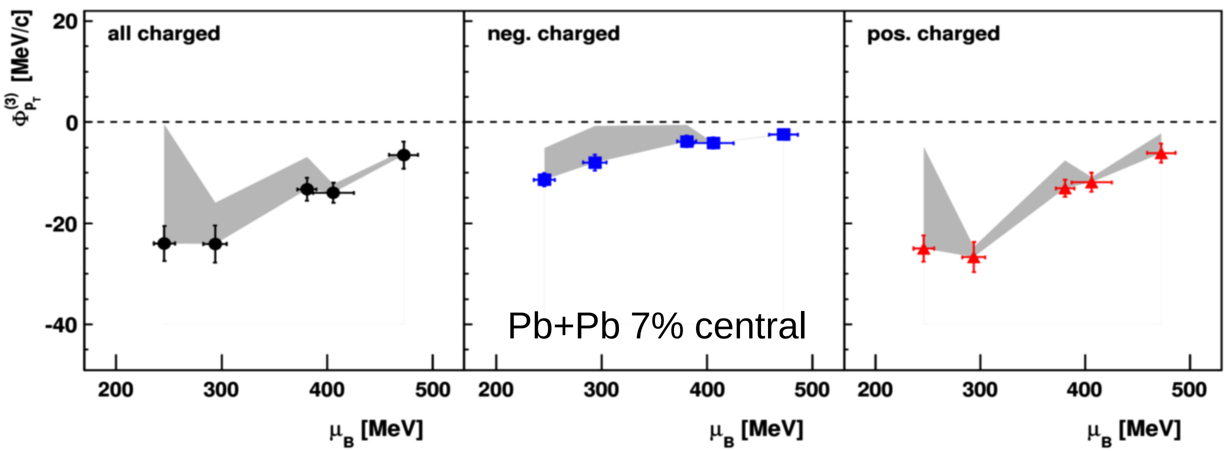
$\Phi_{p_T}^{(3)}$: 3rd moment of <p_T> fluctuations

$$\Phi^{(n)}_{p_T} = \left(\frac{\langle Z^2_{p_T}\rangle}{\langle N\rangle}\right)^{1/n} - \left(\overline{z^n_{p_T}}\right)^{1/n}$$

K. Grebieszkow & M. Bogusz, NA49 preliminary

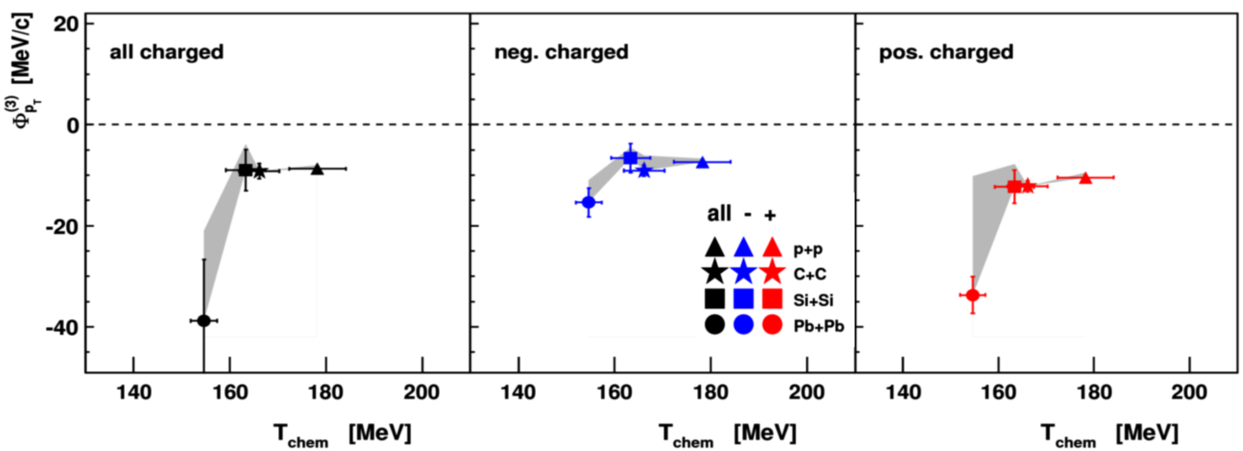
$\Phi_{pT}^{(3)}$ has strongly intensive property like Φ_{pT}

(S.Mrowczynski,Phys.Lett.B465,8(1999))



no quantitative predictions

systematic errors large

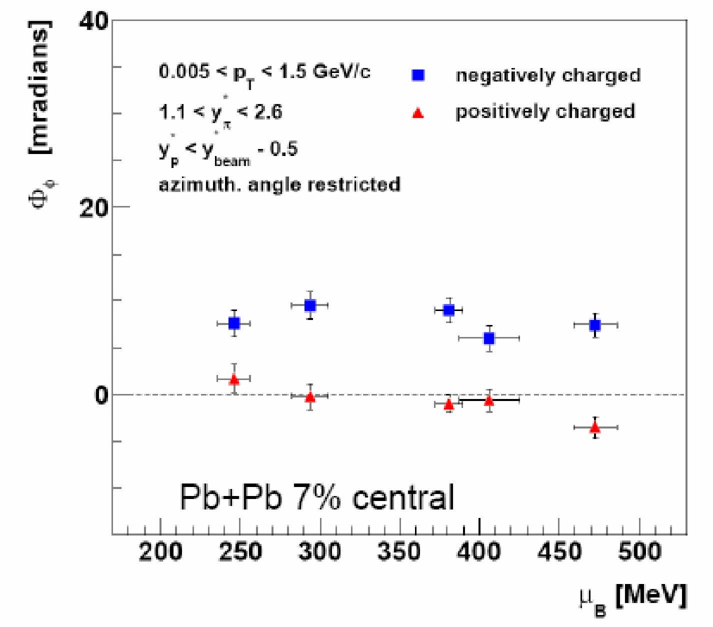


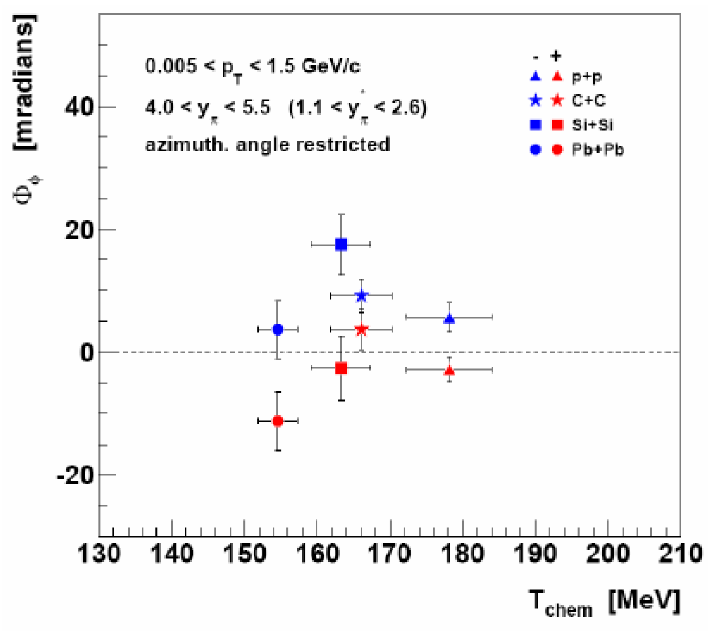
no indication of CP fluctuations

Φ_ϕ : fluctuations of average azimuthal angle

- plasma instabilities (S.Mrowczynski, Phys.Lett. B314,118(1993))
- flow fluctuations (S.Mrowczynski,E.Suryak,Act.Phys.Pol.B34,4241(2003)
- onset of deconfinement, critical point

K. Grebieszkow, NA49 preliminary





- no significant energy (μ_B) dependence in central collisions
- hint of maximum in nuclear size (T) dependence ?

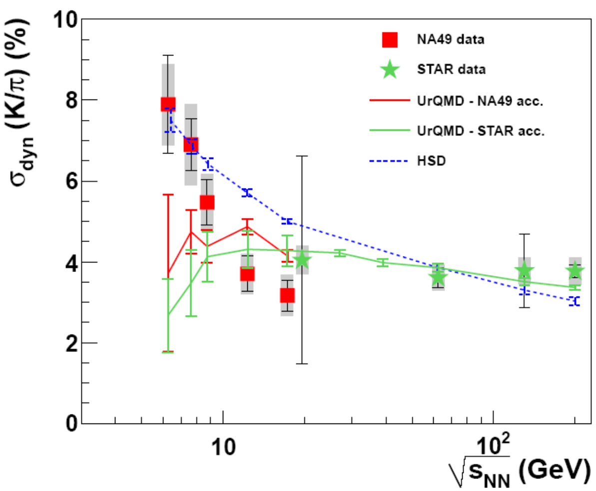
Event-by-event particle ratio fluctuations

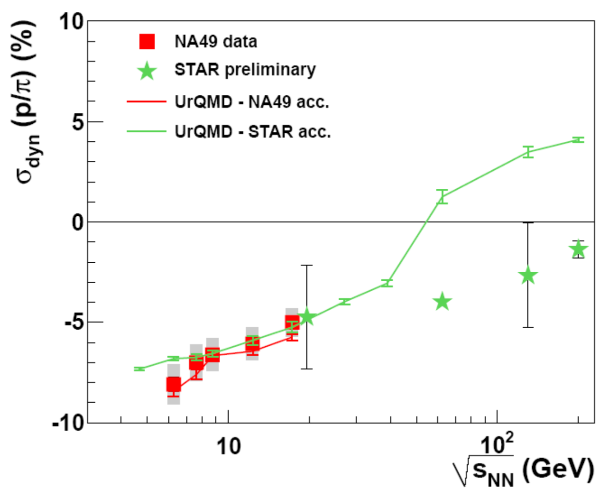
E-by-E fit of particle ratios to dE/dx spectra in real and mixed events

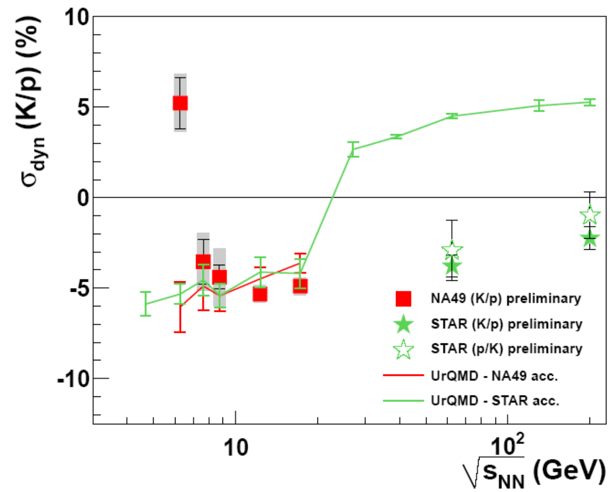
$$\sigma_{dyn} = \mathrm{sign}(\sigma^2_{data} - \sigma^2_{mix})\sqrt{\left|\sigma^2_{data} - \sigma^2_{mix}\right|} \quad ; \quad \sigma^2_{dyn} = \left|\nu_{dyn}\right|$$

NA49 data: PRC79,044910(2009)

T. Schuster, NA49 preliminary







rise towards low √s
deconfinement ?

negative values
due to nucleon
resonances (UrQMD)

sign change at low √s

UrQMD calculations at RHIC energies courtesy of Hui Wang

Successor and extension of NA49

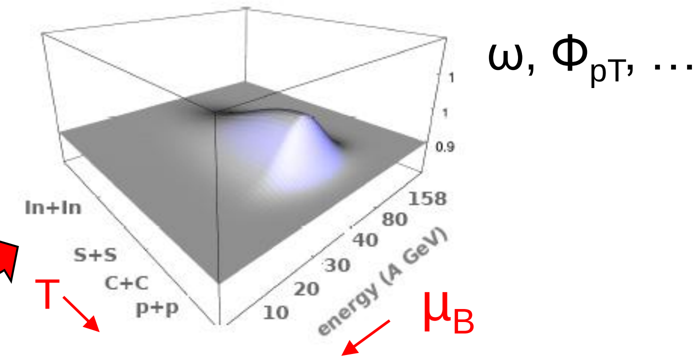
NA61/SHINE physics program:

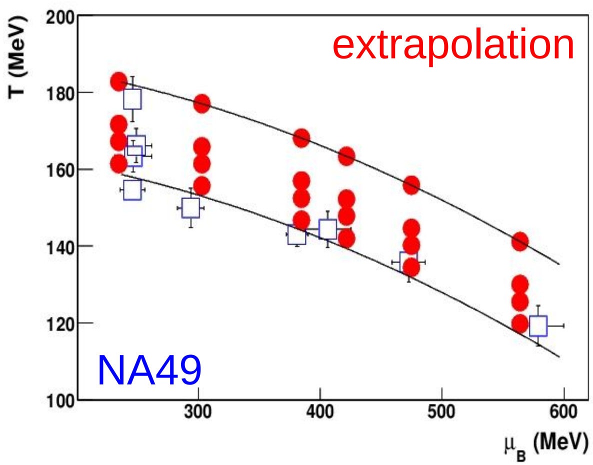
- Critical Point and Onset of Deconfinement,
- Particle yield measurements for
  - Neutrino physics
  - Cosmic-ray physics

Proposal: CERN-SPSC-2006-034, SPSC-P-330 (November 3, 2006)
LoI: CERN-SPSC-2006-001, SPSC-I-235 (January 6, 2006)
EoI: CERN-SPSC-2003-031, SPSC-EOI-001 (November 21, 2003)

Physics goals

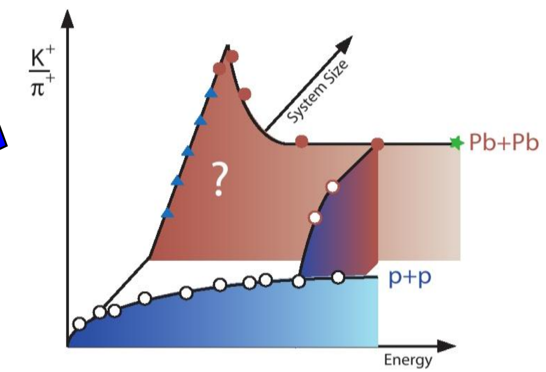
- Critical point and onset of deconfinement (scan in energy and system size A)





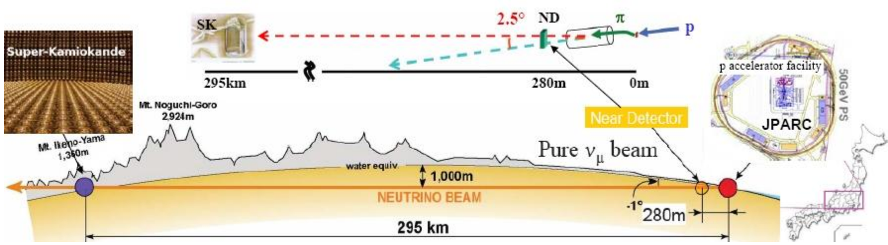
critical point:
hill of fluctuations

onset of deconfinement:
disappearance of horn etc.



- Particle yield measurements for neutrino and cosmic ray physics

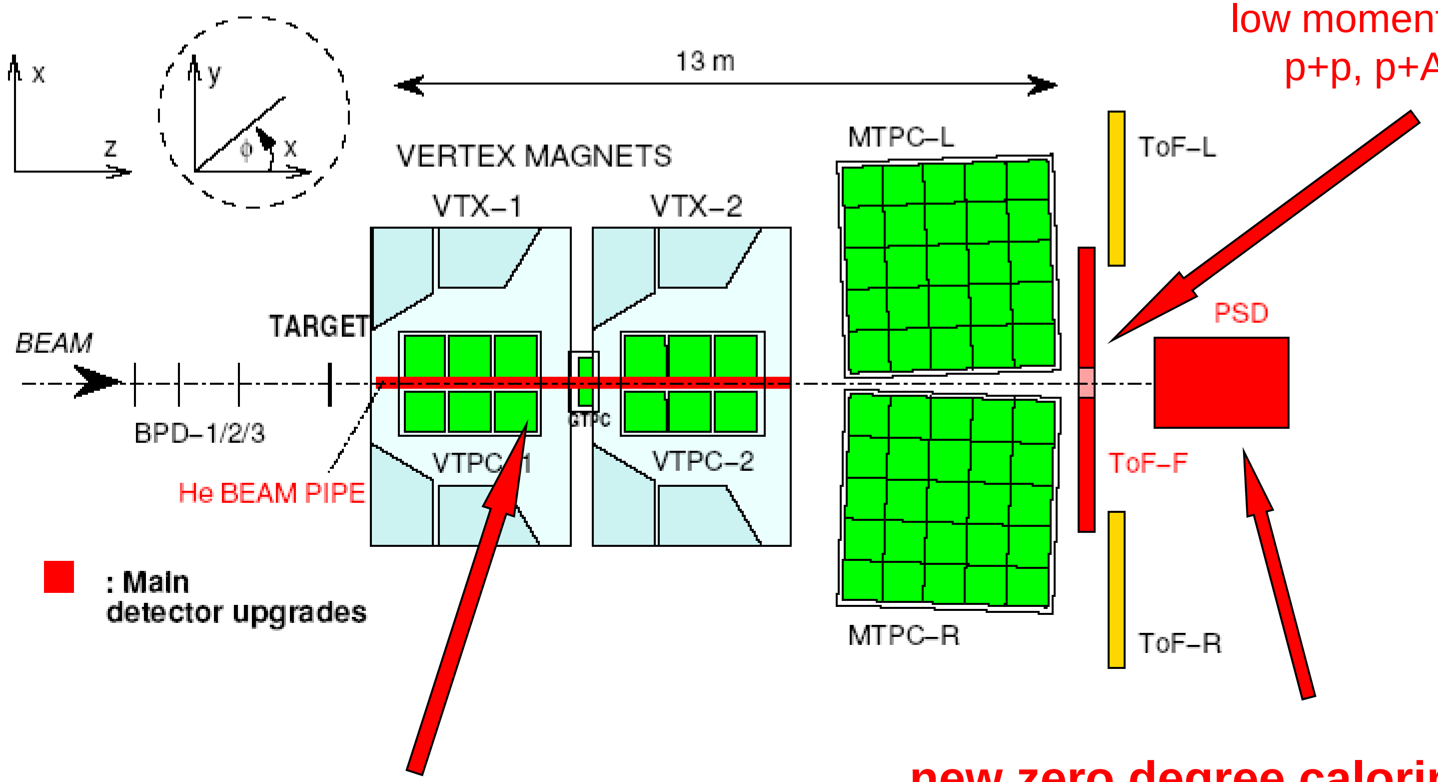
Precise spectra in p+C at 31 GeV/c needed to calculate initial neutrino flux



Main detector upgrades

new TPC readout and DAQ
increase in event rate x 10 (80 Hz)

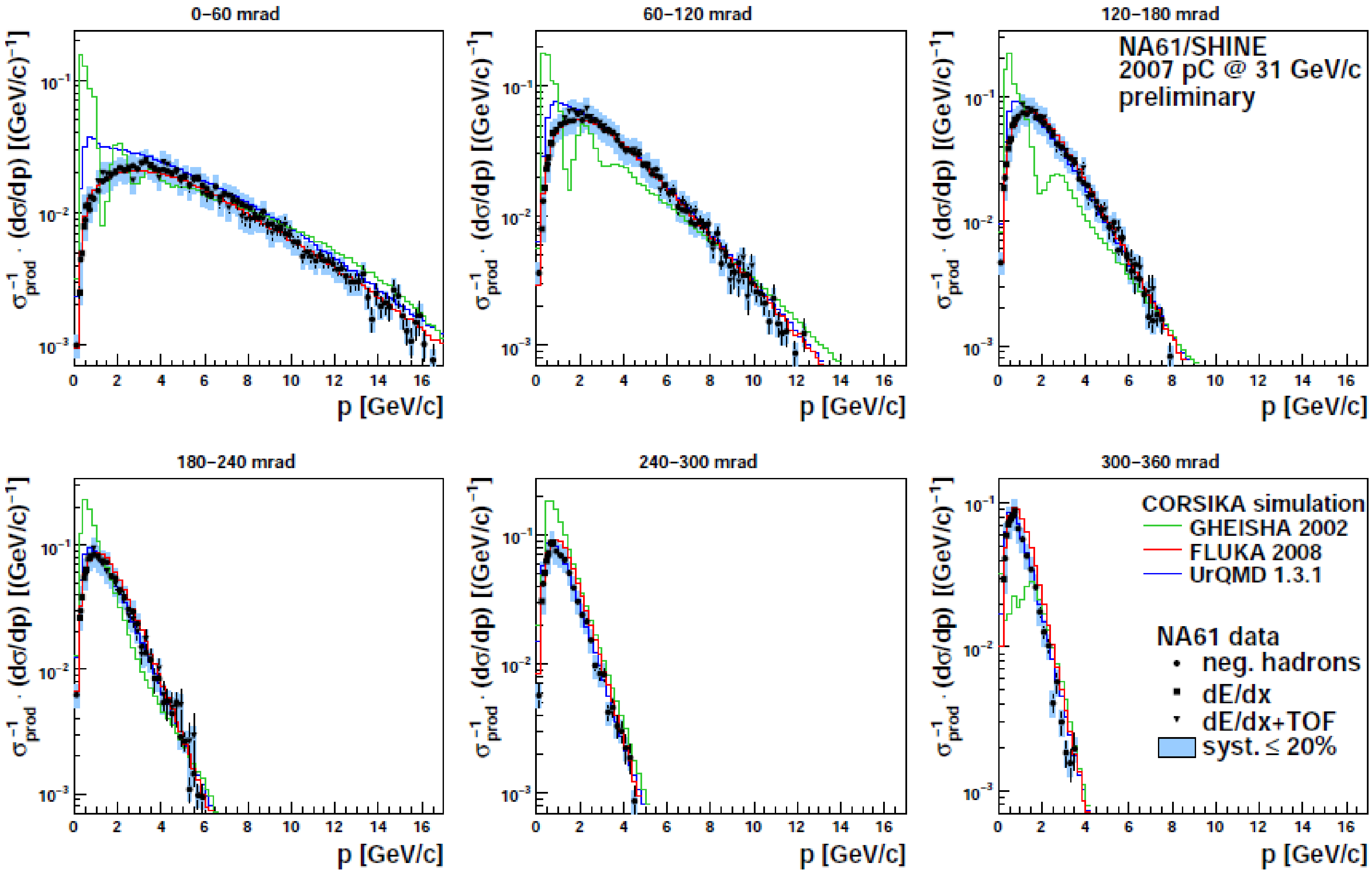
forward TOF system
low momentum tracks in p+p, p+A collisions



new zero degree calorimeter PSD
single nucleon resolution

He beam pipe
reduction of δ-ray background (x10)

First physics results (2007 pilot run)



p+C @ 31 GeV

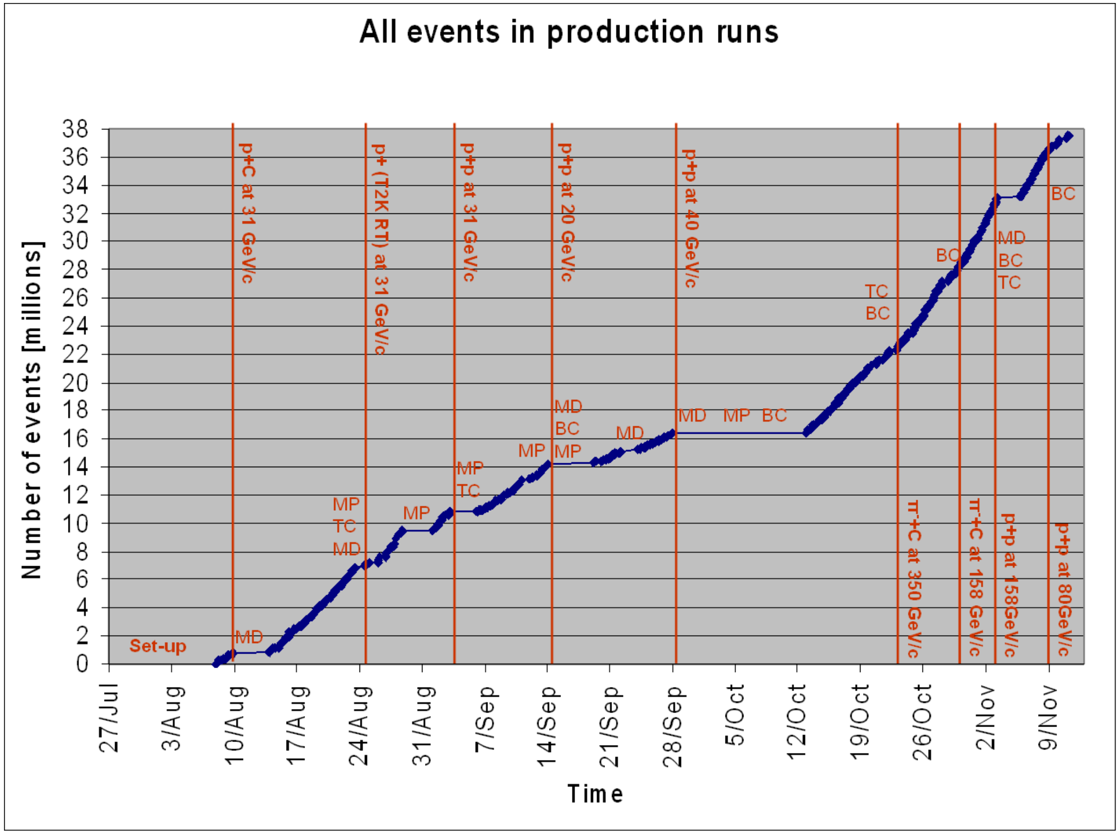
Physics runs: 2009 & 2010

Registered in 2009

p+C at 31 GeV/c
p+(T2K RT) at 31 GeV/c
pion+C at 158 GeV/c
pion+C at 350 GeV/c
p+p at 20 GeV/c
p+p at 31 GeV/c
p+p at 40 GeV/c
p+p at 80 GeV/c
p+p at 158 GeV/c

Registered in 2010:

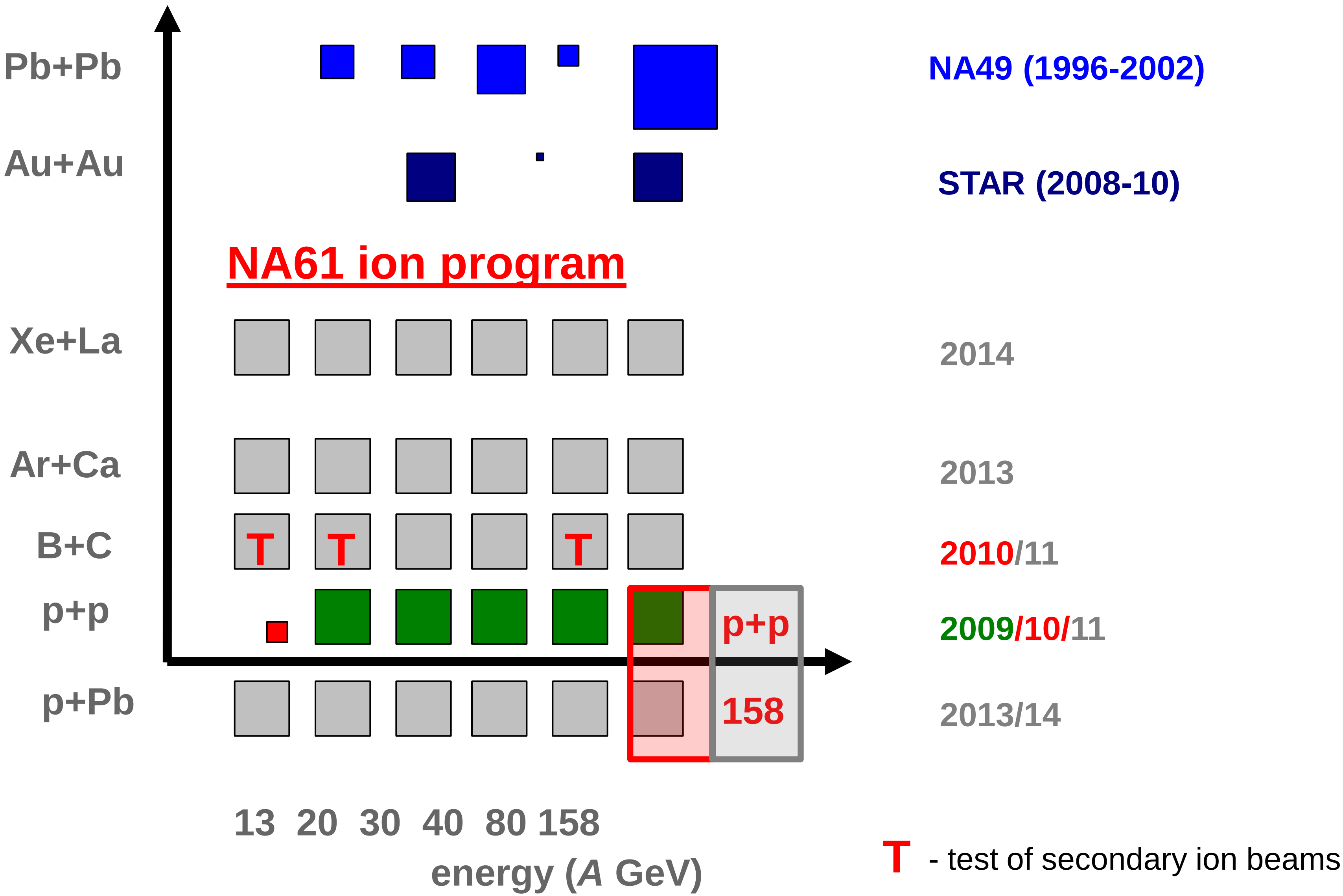
p+(T2K RT) at 31 GeV/c
p+p at 13 GeV/c
p+p at 158 GeV/c in progress



MD – Machine development
MP - Machine problems
TC - Target Change
BC - Beam Change

Data analysis in progress

Progress and plans in data taking for CP & OD



Conclusion

Indications for the onset of deconfinement observed by NA49 at the low SPS energies

Confirmation of NA49 results on the onset of deconfinement by STAR at RHIC in progress

Search for critical point of strongly interacting matter by NA49 presently inconclusive

NA61/SHINE has started 2D (T- μ_B) scan of QCD phase diagram

Detector performing well, data taking for OD & CP in progress

NA49 collaboration

T. Anticic[22], B. Baatar[8], D. Barna[4], J. Bartke[6], H. Beck[9], L. Betev[10], H. Białkowska[19], C. Blume[9], M. Bogusz[21], B. Boimska[19], J. Book[9], M. Botje[1], P. Bunčić[10], T. Cetner[21], P. Christakoglou[1], P. Chung[18], O. Chvála[14], J.G. Cramer[15], V. Eckardt[13], Z. Fodor[4], P. Foka[7], V. Friese[7], M. Gaździcki[9,11], K. Grebieszkow[21], C. Höhne[7], K. Kadija[22], A. Karev[10], V.I. Kolesnikov[8], M. Kowalski[6], D. Kresan[7], A. László[4], R. Lacey[18], M. van Leeuwen[1], M. Maćkowiak[21], M. Makariev[17], A.I. Malakhov[8], M. Mateev[16], G.L. Melkumov[8], M. Mitrovski[9], St. Mrówczyński[11], V. Nicolic[22], G. Pálla[4], A.D. Panagiotou[2], W. Peryt[21], J. Pluta[21], D. Prindle[15], F. Pühlhofer[12], R. Renfordt[9], C. Roland[5], G. Roland[5], M. Rybczyński[11], A. Rybicki[6], A. Sandoval[7], N. Schmitz[13], T. Schuster[9], P. Seyboth[13], F. Siklér[4], E. Skrzypczak[20], M. Słodkowski[21], G. Stefanek[11], R. Stock[9], H. Ströbele[9], T. Susa[22], M. Szuba[21], M. Utvić[9], D. Varga[3], M. Vassiliou[2], G.I. Veres[4], G. Vesztergombi[4], D. Vranić[7], Z. Włodarczyk[11], A. Wojtaszek-Szwarc[11]

[1]NIKHEF, Amsterdam, Netherlands. [2]Department of Physics, University of Athens, Athens, Greece. [3]Eötvös Loránt University, Budapest, Hungary [4]KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary. [5]MIT, Cambridge, USA. [6]H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Cracow, Poland. [7]Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany. [8]Joint Institute for Nuclear Research, Dubna, Russia. [9]Fachbereich Physik der Universität, Frankfurt, Germany. [10]CERN, Geneva, Switzerland. [11]Institute of Physics, Jan Kochanowski University, Kielce, Poland. [12]Fachbereich Physik der Universität, Marburg, Germany. [13]Max-Planck-Institut für Physik, Munich, Germany. [14]Inst. of Particle and Nuclear Physics, Charles Univ., Prague, Czech Republic. [15]Nuclear Physics Laboratory, University of Washington, Seattle, WA, USA. [16]Atomic Physics Department, Sofia Univ. St. Kliment Ohridski, Sofia, Bulgaria. [17]Institute for Nuclear Research and Nuclear Energy, BAS, Sofia, Bulgaria. [18]Department of Chemistry, Stony Brook Univ. (SUNYSB), Stony Brook, USA. [19]Institute for Nuclear Studies, Warsaw, Poland. [20]Institute for Experimental Physics, University of Warsaw, Warsaw, Poland. [21]Faculty of Physics, Warsaw University of Technology, Warsaw, Poland. [22]Rudjer Boskovic Institute, Zagreb, Croatia.

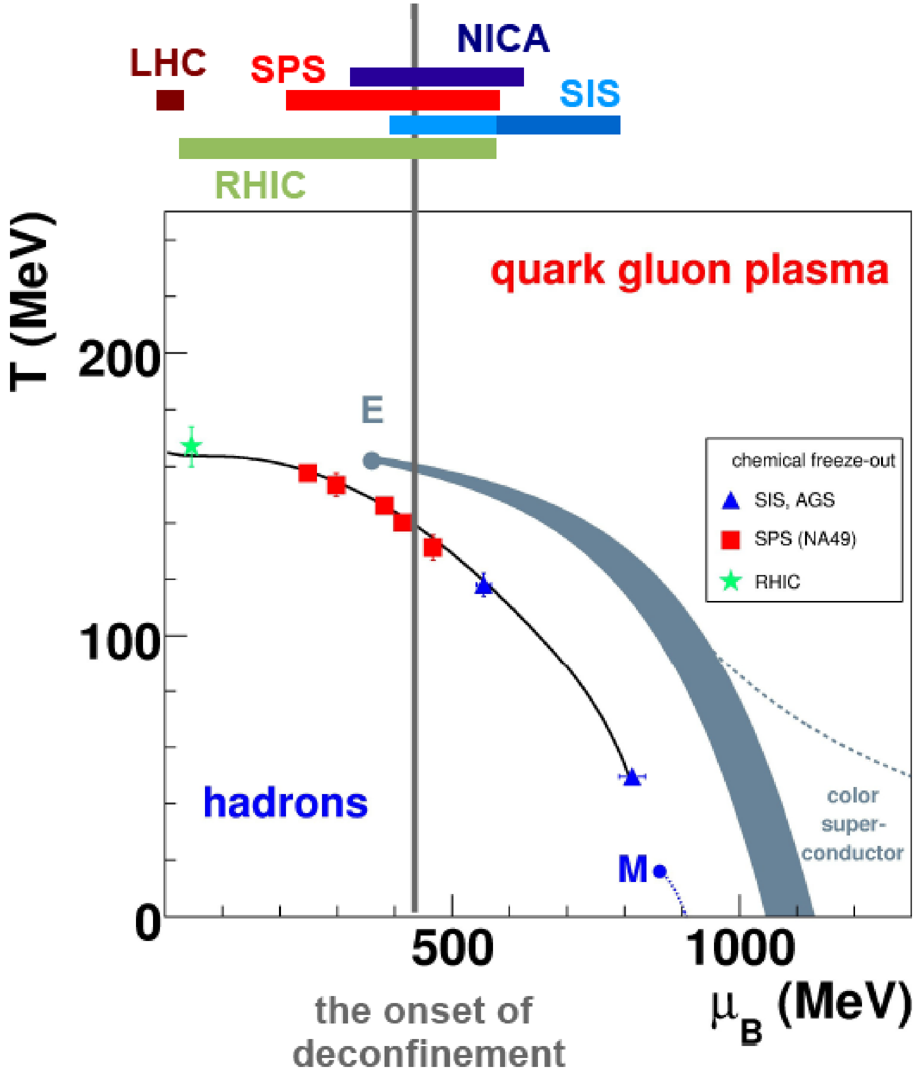
NA61/SHINE collaboration

NA61: 130 physicists from 24 institutes and 13 countries:

University of Athens, Athens, Greece
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
KFKI IPNP, Budapest, Hungary
Jagiellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Fachhochschule Frankfurt, Frankfurt, Germany
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
Forschungszentrum Karlsruhe, Karlsruhe, Germany
Institute of Physics, University of Silesia, Katowice, Poland
Jan Kochanowski Univeristy, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
LPNHE, Universites de Paris VI et VII, Paris, France
Faculty of Physics, University of Sofia, Sofia, Bulgaria
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
KEK, Tsukuba, Japan
Soltan Institute for Nuclear Studies, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
University of Warsaw, Warsaw, Poland
Universidad Tecnica Federico Santa Maria, Valparaiso, Chile
Rudjer Boskovic Institute, Zagreb, Croatia
ETH Zurich, Zurich, Switzerland

additional / backup slides

QCD critical point searches – future experimental landscape



partly complementary programs
planned at CERN SPS 2011
BNL RHIC 2010
DUBNA NICA 2016
GSI SIS-CBM 2017 ?

strong points of NA61:

- tight constraint on spectators
- high event rate at all SPS energies
- flexibility to change A and energy

Strong points of BNL/STAR:

- full uniform azimuthal acceptance
- excellent TOF identification
- low track density

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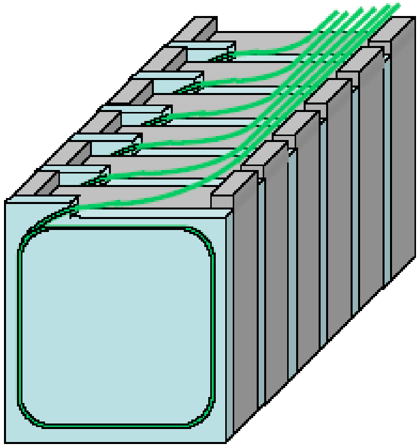
Experimental landscape of complementary programs of nucleus-nucleus collisions around the SPS energies

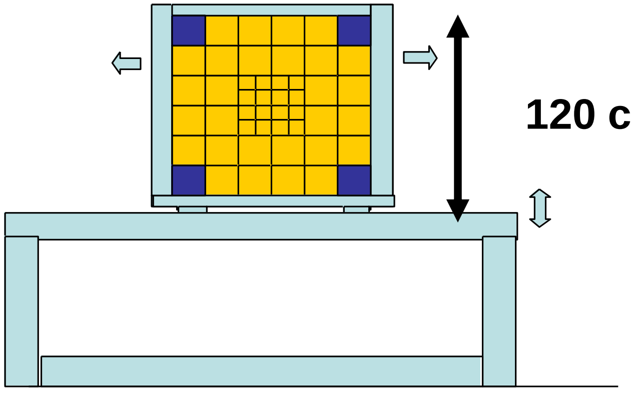
Facility:	**SPS**	**RHIC**	**NICA**	**SIS-100 (SIS-300)**
Exp.:	**NA61**	**STAR PHENIX**	**MPD**	**CBM**
Start:	**2011**	**2010**	**2016**	**2017 (2019)**
Pb Energy: (GeV/(N+N))	**4.9-17.3**	**7.7- 39**	**≤11**	**≤5 (<8.5)**
Event rate: (at 8 GeV)	**100 Hz**	**3-30 Hz**	**≤10 kHz**	**≤10 MHz**
Physics:	**CP&OD**	**CP&OD**	**OD&HDM**	**HDM (OD)**

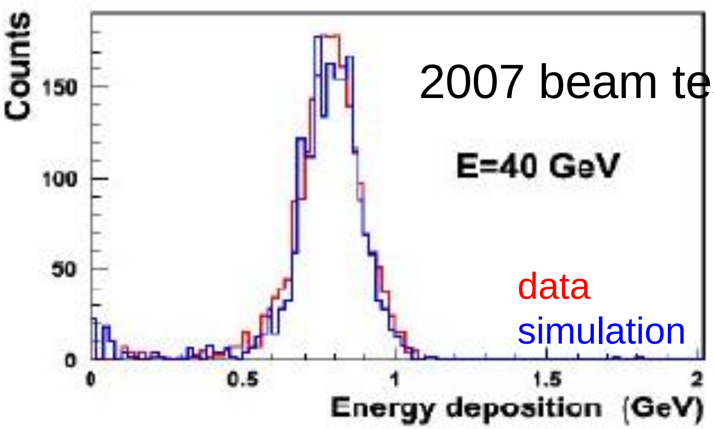
CP – critical point
OD – onset of deconfinement, mixed phase, 1st order PT
HDM – hadrons in dense matter

PSD – Projectile Spectator Detector (completion for 2012)

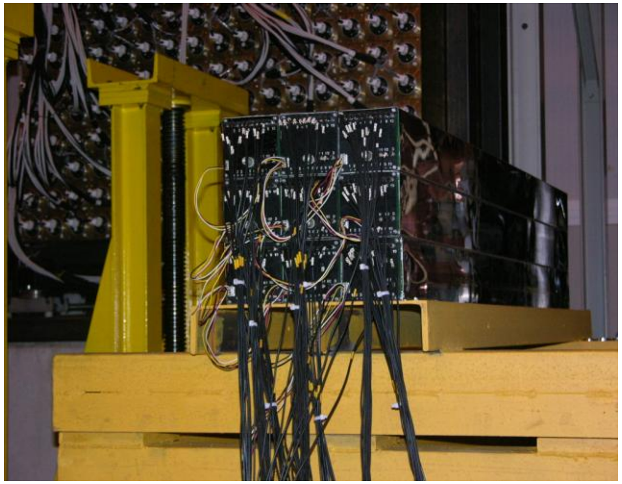


- 60 lead/scintillator sandwiches
- 10 longitudinal sections
- 6 WLS-fiber/MAPD
- 10 MAPDs/module
- 10 Amplifiers with gain~40



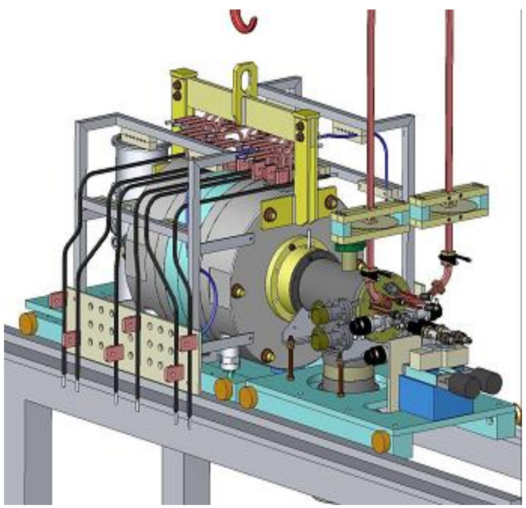


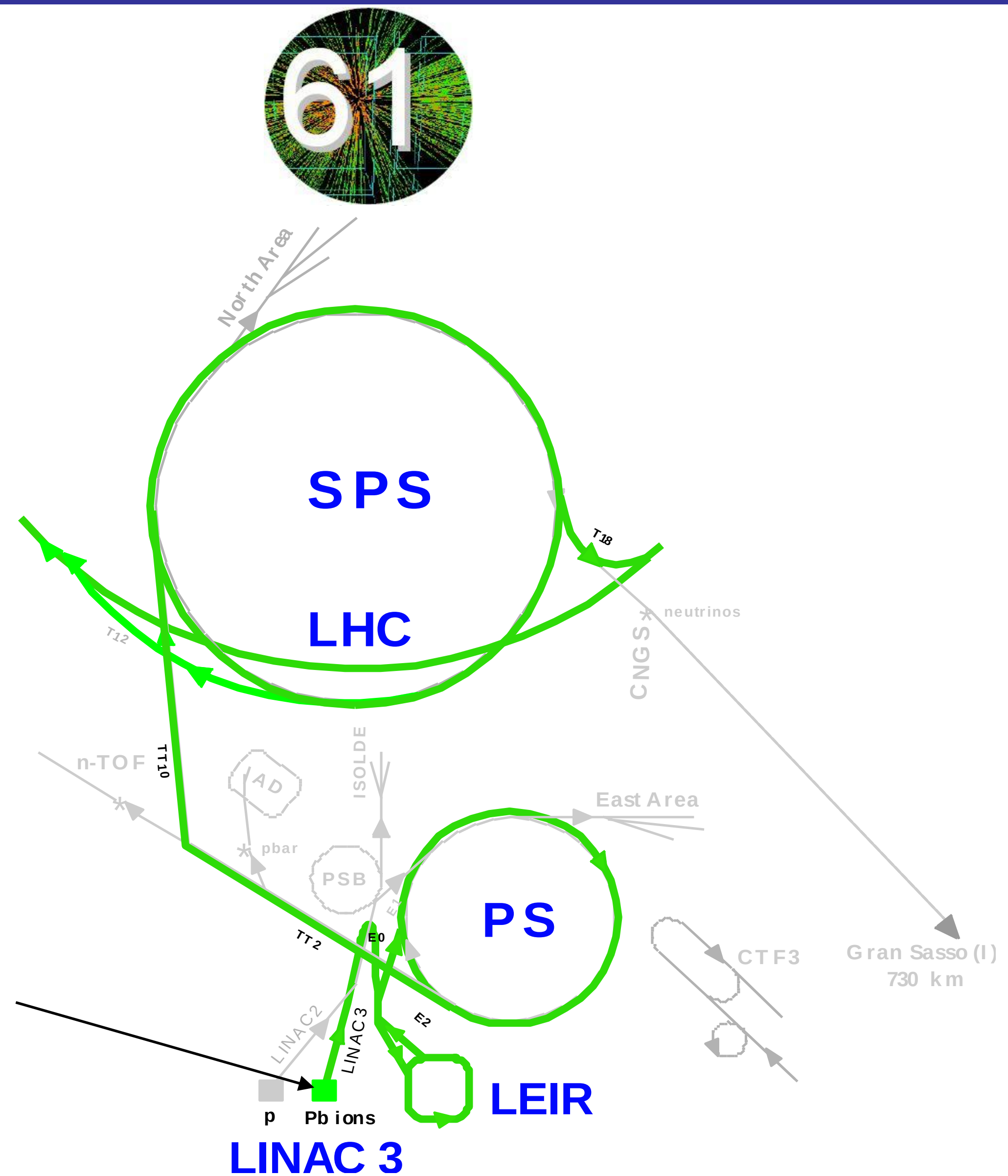
$\sigma(E)/E = 36\%/\sqrt{E(GeV)} + 0.2\%$



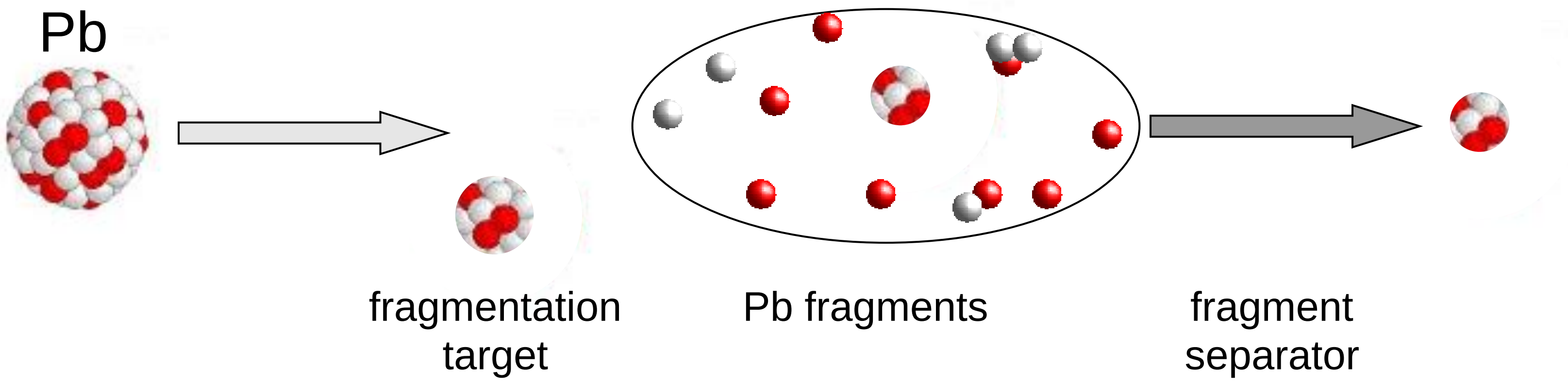
Primary Ar, Xe and Pb beams

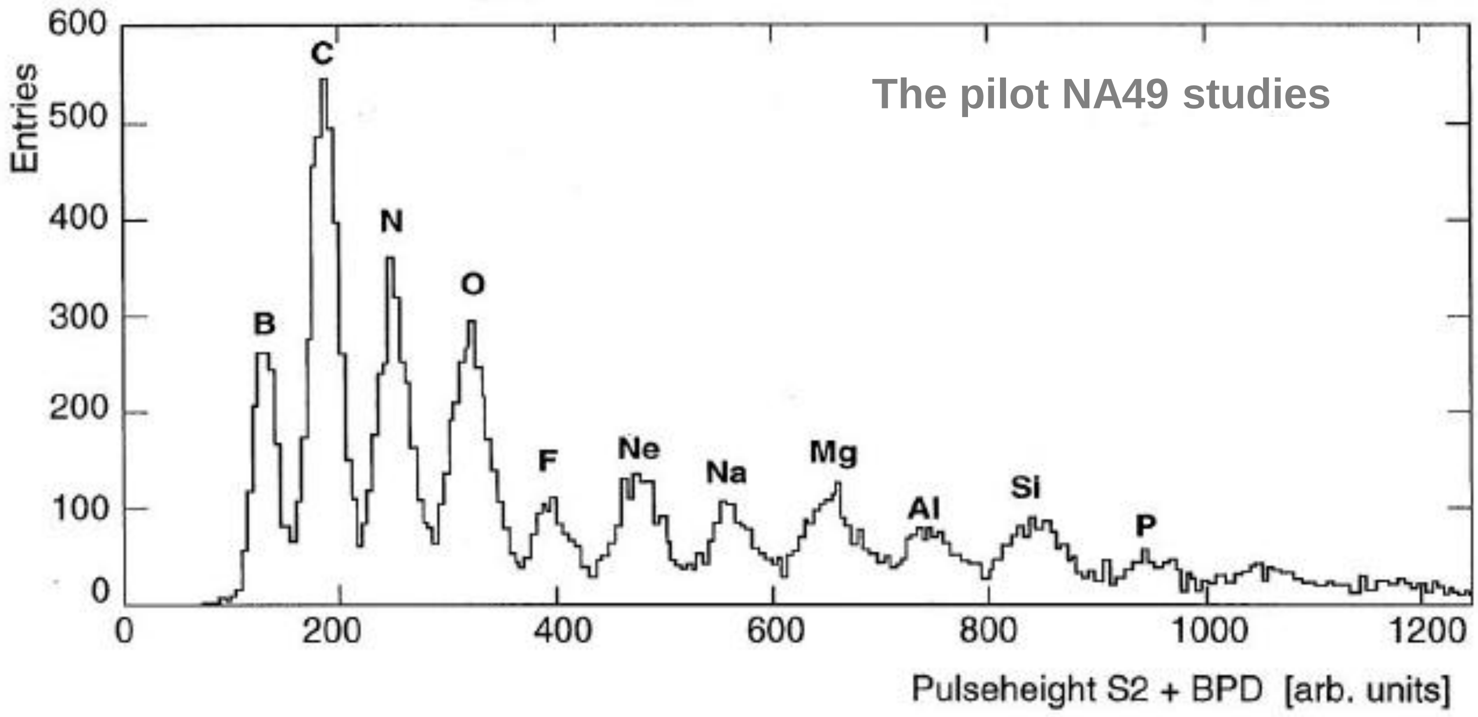
ECR ion source



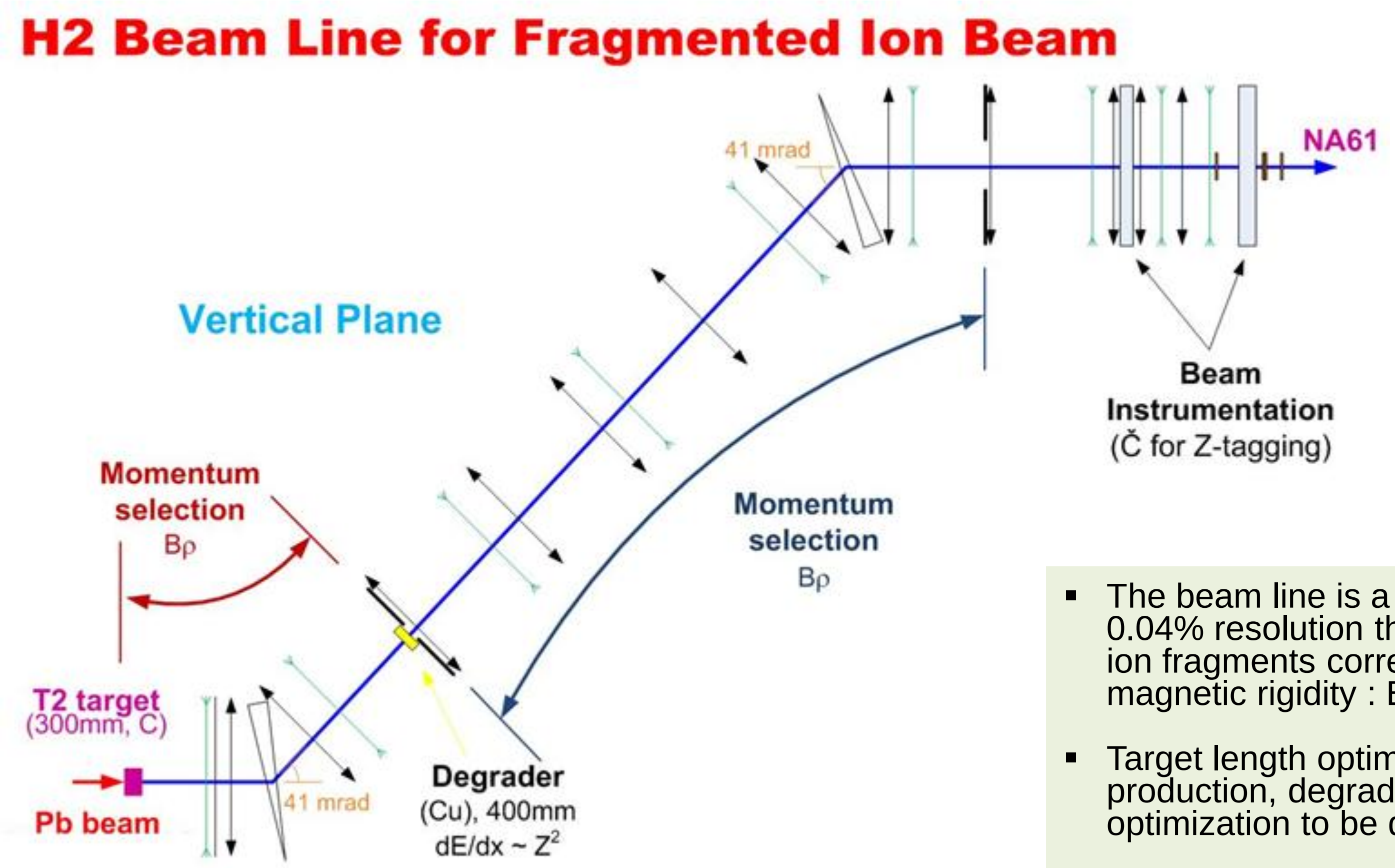


Secondary Boron beam: basic idea





Secondary Boron beam: fragment separator



- The beam line is a double spectrometer with 0.04% resolution that helps to separate the ion fragments corresponding to a selected magnetic rigidity : Bρ
- Target length optimized to fragment production, degrader with variable length – optimization to be determined from the tests

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NA61/SHINE data taking plan

	Beam Primary	Beam Secondary	Target	Energy (A GeV)	Year	Duration days/MDs	Physics	Status
	p	p	p	400 158	2010	77 d	High p_T	*recommended*
FR test-1	Pb	^{11}B	none	20,80 20,80	2010	10 MDs	FS test-1	*to be discussed*
	p	p	Pb	400 158	2011	77 d	High p_T	*recommended*
secondary (FR test-2)	Pb	^{11}B	C	10,20,30,40,80,158 10,20,30,40,80,158	2011	20 d	FS test-2	*to be discussed*
	p	p	Pb	400 10,20,30,40,80,158	2012	6x8 d	CP,OD	*recommended*
primary	Ar		Ca	10,20,30,40,80,158	2012	6x8 d	CP,OD	*recommended*
(secondary)	Pb	^{11}B	C	10,20,30,40,80,158 10,20,30,40,80,158	2013	6x10 d	CP,OD	*to be discussed*
primary	Xe		La	10,20,30,40,80,158	2014	6x8 d	CP,OD	*to be discussed*